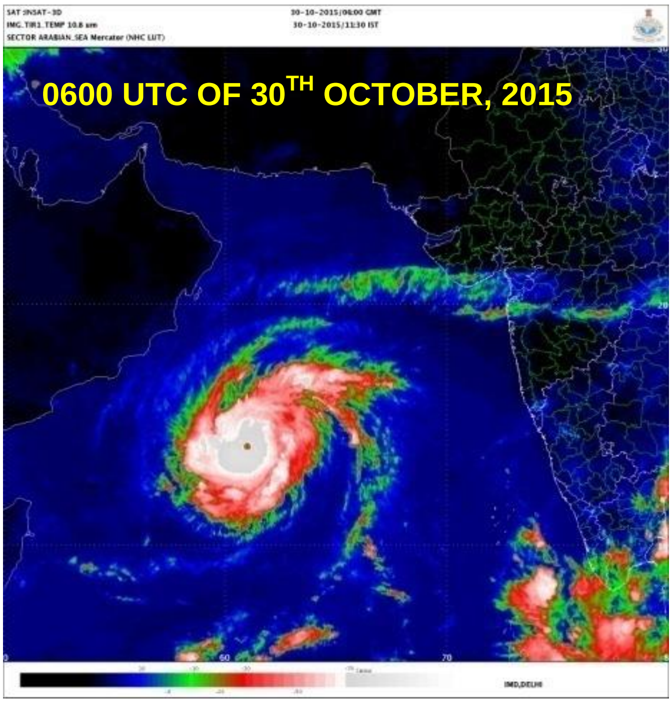
WMO/ESCAP
PANEL ON TROPICAL CYCLONES
ANNUAL REVIEW 2015



SATELLITE IMAGERY OF EXTREMELY SEVERE CYCLONIC STORM, CHAPALA OVER ARABIAN SEA

WORLD METEOROLOGICAL ORGANISATION
AND
ECONOMIC AND SOCIAL COMMISSION
FOR ASIA AND THE PACIFIC

WMO **ESCAP**

WMO/ESCAP
PANEL ON TROPICAL CYCLONES
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PREFACE

First commenced in 1997, the publication of ***WMO/ESCAP Panel*** - *Annual Review* has entered **nineteenth** year of issue for the year 2015. Considerable efforts have gone into producing this document in order to make it useful scientifically and informative for the members of panel. Panel Members are encouraged to make more contributions for further improvement of this publication.

WMO and ***ESCAP*** have played a commendable role in disaster mitigation efforts in the Panel region through continued interaction with the governments of the member countries. There is increasing realization that disaster mitigation effort must encompass all spheres including scientific research on natural hazards, establishment of integrated-all-hazard early warning system and most importantly, empowering communities to be self reliant for timely and proper response to warnings. Despite rapid technological advances made in the recent past, the problem of generating accurate weather forecasts and associated warnings/ advisories and their timely dissemination to the communities at highest risk continues to be a great challenge. In order to make the early warning system more effective, it is essential that the Panel Members take new initiatives. The basic aim of the panel is to improve the quality and content of cyclone warnings, devise methods for quick dissemination of warnings and flood advisories and ensure proper response by concerned agencies and the community.

This review highlights the achievements made during the year, 2015 in the region in pursuance of the goals set out by the ***WMO / ESCAP*** *Panel* and the activities of other international and national organisations in support of the above tasks, within the overall objective of mitigating the impact of natural hazards. I would like to express my sincere thanks to all the Panel Members for their valuable inputs and contributions and hope for the same in future.

M. Mohapatra
Chief Editor

WMO AND THE WMO / ESCAP PANEL ON TROPICAL CYCLONES

WORLD METEOROLOGICAL ORGANIZATION (WMO)

The World Meteorological Organisation (WMO), of which 185 States and Territories are Members, is a specialised agency of the United Nations. The objectives of the organisation are:

- To facilitate international co-operation in the establishment of networks of Stations and Centres to provide Meteorological and Hydrological services and observations;
- To promote the establishment and maintenance of systems for the rapid exchange of meteorological and related information;
- To promote standardisation of meteorological and related observations and ensure the uniform publication/circulation of observations and statistics;
- To further the application of meteorology to aviation, shipping, water problems, agriculture and other human activities;
- To promote activities in operational hydrology and to further close co-operation between Meteorological and Hydrological Services and
- To encourage research and training in meteorology and, as appropriate, in related fields and to assist in co-ordinating the international aspects of such research and training.

ECONOMIC AND SOCIAL COMMISSION FOR ASIA AND THE PACIFIC (ESCAP)

The Economic and Social Commission for Asia and the Pacific (ESCAP) aims to initiate and participate in measures for concerted action towards the development of Asia and the Pacific, including the social aspects of such development, with a view to raising the level of economic activity and standards of living and maintaining and strengthening the economic relations of countries and territories in the region, both among themselves and with other countries in the world. The commission also:

- Provides substantive services, secretariats and documentation for the Commission and its subsidiary bodies;
- Undertakes studies, investigations and other activities within the commission's terms of reference;
- Provides advisory services to Governments;
- Contributes to the planning and organisation of programmes of technical co-operations and acts as executing agency for those regional projects decentralised to it.

WMO / ESCAP PANEL ON TROPICAL CYCLONES

Huge loss of human life, damage to property and unbearable sufferings of human beings caused by tropical cyclones in coastal areas in various parts of the globe like Atlantic, Pacific, China Sea and North Indian Ocean (NIO) coast are regular features.

The disaster potential due to cyclones is particularly high in the NIO comprising of the Bay of Bengal & the Arabian Sea region, which is being associated with high storm surge, which is the greatest killer in a cyclone. This region has the distinction of having experienced the world's highest recorded storm tide of 41 feet (1876 Bakherganj cyclone near Megna estuary, Bangladesh) followed by 13 metres over West Bengal coast on 7th

October, 1737 in association with another super cyclone . Past records show that very heavy loss of life due to tropical cyclones have occurred in the coastal areas surrounding the Bay of Bengal. In the recent past, during the year 1998, the state of Gujarat in India experienced the impact of a very severe cyclonic storm, which crossed coast north of Porbandar (42830) on June 9, 1998 and caused huge damage to public property near Kandla Port (42639). A Super Cyclonic Storm that crossed east coast of India near Paradip (42976) in Orissa state on October 29, 1999 took a toll of 9885 lives and caused huge damage to property in 12 districts of the state. Apart from causing large-scale devastation to agriculture and plantation crops, it also affected entire infrastructure on communication, power and transport. The storm surge of 5-6 m height was experienced in areas close to and southwest of Paradip. This cyclone was century's most intense cyclone and its unusual feature was that it remained practically stationary after crossing coast and battered the State of Orissa for 36 hours. In June, 2007 another super cyclone 'Gonu' developed over southeast Arabian Sea, moved north-westward, crossed Oman coast and then entred into Gulf of Oman and made second landfall over Iran coast. It caused huge damage to the property and loss of lives in Oman and Iran. The very severe cyclonic storm, 'Nargis' crossed Myanmar coast near Irrawaddy delta on 2nd May 2008 and caused loss of about 138,000 lives in Myanmar.

Realising the importance of an effective cyclone warning and disaster mitigation machinery in the region, WMO and ESCAP jointly established the Panel on Tropical Cyclones (PTC) in 1972 as an inter-Governmental body. Its membership comprises the countries affected by tropical cyclones in the NIO. Its Member countries are Bangladesh, India, Maldives, Myanmar, Pakistan, Sri Lanka, Sultanate of Oman and Thailand.

The Panel is one of the six regional tropical cyclone bodies established as part of the WMO Tropical Cyclone Programme (TCP) namely Miami, Honolulu, Tokyo, New Delhi, La Reunion and Nadi that aims at promoting and co-ordinating the planning and implementation of measures to mitigate tropical cyclone disaster.

It also aims to initiate and participate in measures for concerted action towards the development of Asia and the Pacific including social aspects of such developments, with a view to raising the level of economic activity and standards of living and maintaining and strengthening the economic relations of countries and territories in the region, both among themselves and with other countries in the world.

The first session of WMO/ESCAP Panel on Tropical Cyclones was convened in Bangkok, Thailand in January 1973. The functions of the Panel are:

- ► To review regularly the progress in various fields of tropical cyclone damage prevention;
- ► To recommend to the member countries plans and measures for the improvement of community preparedness and disaster prevention;
- ► To promote, prepare and submit to member countries plans for co-ordination of research programmes and activities on tropical cyclones;
- ► To facilitate training of personnel from member countries in tropical cyclone forecasting and warning, flood hydrology and its control within the region;
- ► To plan for co-ordination of research programmes and activities concerning tropical cyclones within member countries;

- ► To prepare and submit, at the request and on behalf of the member countries requests for technical, financial and other assistance offered under United Nations Development Programme (UNDP) and by other organisations and contributors and
- ► To consider, upon request, possible sources of financial and technical support for such plans and programmes.

In carrying out these functions, the PTC committee maintains and implements action programmes under the five components of meteorology, hydrology, disaster prevention and preparedness, training and research with contributions and co-operation from its Members and assistance by the UNDP, ESCAP, WMO and other agencies.

The Panel at its twelfth session in 1985 at Karachi (Pakistan) adopted a comprehensive cyclone operational plan for this region. The basic purpose of the operational plan is to facilitate the most effective tropical cyclone system for the region with existing facilities. The plan defined the sharing of responsibilities among Panel countries for the various segments of the system and recorded the co-ordination and co-operation achieved. The plan also recorded the agreed arrangements for standardization of operational procedures, efficient exchange of various data and its archival related to tropical cyclone warnings, issue of a tropical weather outlook and cyclone advisories from a central location having the required facilities for this purpose, for the benefit of the region and strengthening of the operational plan. Further the Panel agreed upon the issue of tropical cyclone advisory bulletin for use of aviation as per recommendation No. 1/21 of International Civil Aviation Organisation (ICAO) in its 12th meeting of 161st session held at Montreal, Canada during 09-26 September, 2002

The operational plan is evolutionary in nature. Its motivation is to update or raise the text of the plan from time to time by the Panel and each item of information given in the annexes of the plan to be kept up to date by the member country concerned.

RSMC- Tropical Cyclones, New Delhi:

Regional Specialized Meteorological Centre (RSMC) - Tropical Cyclones, New Delhi, which is co-located with Cyclone Warning Division of IMD and came into the existence in 1988 as per the recommendation of first session of WMO/ESCAP Panel on Tropical cyclones held in January,1973. It has the responsibility of issuing Tropical Weather Outlook and Tropical Cyclone Advisories for the benefit of the countries in the World Meteorological Organization (WMO)/ Economic and Social Co-operation for Asia and the Pacific (ESCAP) Panel region bordering the Bay of Bengal and the Arabian Sea, namely, Bangladesh, Maldives, Myanmar, Pakistan, Sultanate of Oman, Sri Lanka and Thailand. It has also the responsibilities as a Tropical Cyclone Advisory Centre (TCAC) to provide Tropical Cyclone Advisories to the designated International Airports as per requirement of International Civil Aviation Organization (ICAO).

The area of responsibility of RSMC- New Delhi covers Sea areas of north Indian Ocean (north of equator between 45^0 E and 100^0 E) and includes the member countries of WMO/ESCAP Panel on Tropical Cyclones viz. Bangladesh, India, Maldives, Myanmar, Pakistan, Sri Lanka, Sultanate of Oman, Thailand and Yemen. The Yemen became member of the Panel in 2016.

The broad functions of RSMC- Tropical Cyclones, New Delhi are as follows:

- Round the clock watch on weather situations over the entire north Indian Ocean.

- Analysis and processing of global meteorological data for diagnostic and prediction purposes.
- Detection, tracking and prediction of cyclonic disturbances in the Bay of Bengal and the Arabian Sea.
- Running of numerical weather prediction models for tropical cyclone track and storm surge predictions.
- Interaction with National Disaster Management Authority and National Disaster Management, Ministry of Home Affairs, Govt. of India to provide timely information and warnings for emergency support services. RSMC-New Delhi also coordinates with National Institute of Disaster Management (NIDM) for sharing the information related to cyclone warning.
- Implementation of the Regional Cyclone Operational Plan of WMO/ESCAP Panel.
- Issue of Tropical Weather Outlook and Tropical Cyclone Advisories to the Panel countries in general.
- Issue of Tropical Cyclone advisories to International airports in the neighbouring countries for International aviation.
- Collection, processing and archival of all data pertaining to cyclonic disturbances viz. wind, storm surge, pressure, rainfall, damage report, satellite and Radar derived information etc. and their exchange with Panel member countries.
- Preparation of comprehensive annual reports on cyclonic disturbances formed over North Indian Ocean every year.
- Preparation of annual review report on various activities including meteorological, hydrological and disaster preparedness and prevention activities of panel member countries.
- Research on track, structure and intensity monitoring and prediction techniques as well as associated adverse weather including storm surge, heavy rain and gale wind.

COMMITTEE ON WMO/ESCAP PANEL ON TROPICAL CYCLONES (2015 –16)

Chairman	**: Dr. L. S. Rathore (India)**
Vice-Chairman	**: Mr Ali Shareef (Maldives)**
Chairman drafting committee:	**Mr Siri Ranjith Jayasekera (Sri Lanka)**

TECHNICAL SUPPORT UNIT (TSU)
ISLAMABAD, PAKISTAN

Co-ordinator	**: Dr. Ghulam Rasul**
Meteorologist	**: Mr. Imran Akram**

WMO SECRETARIAT FOR
TROPICAL CYCLONE PROGRAMME (TCP)

Mr. Michel Jarraud:	**Secretary General**
Dr.Xu Tang:	**Director, Weather and Disaster Risk Reduction Service**
Dr. Taoyong Peng:	**Chief, TCP Division**

UNITED NATIONS ECONOMIC AND SOCIAL COMMISSION
FOR ASIA AND THE PACIFIC (UNESCAP)

Dr Shamika Sirimanne	**Director/UN-ESCAP** **Information and Communications Technology and Disaster Risk Reduction Division**
Dr. Sanjay K Srivastava	**Chief/UN-ESCAP** **Disaster Risk Reduction Section of the ICT**

INTRODUCTION

Publication of "WMO/ESCAP Panel on Tropical Cyclones–Annual Review commenced with the review for the year 1997. This was as per the decision of the Second Joint Session of the WMO/ESCAP Panel on Tropical Cyclones and Typhoon Committee held at Phuket, Thailand 20-28, February 1997. The present Annual Review-2015 contains primary contribution from the Panel member countries.

Chapter I contains detailed information on national programmes and activities related to meteorology, hydrology, disaster prevention and preparedness, training and research as supplied by Panel Members. Technical and administrative support provided and activities undertaken by the Panel.

A summary of Tropical Cyclones during 2015 is given in the first part of Chapter II. Earlier, tropical cyclones were identified by their geographical locations. From post monsoon season 2004, the practice of naming each tropical cyclone individually has been adopted in the north Indian Ocean basin also. Tropical disturbances are classified as per the practice introduced at Regional Specialised Meteorological Centre (RSMC)–Tropical Cyclones New Delhi. The classification of disturbances is shown in the following Table. The term "Cyclone" used in the present text is a generic term for the five categories of cyclonic disturbances (S.N. 4 to 8) in the Table.

Classification of low-pressure systems at RSMC–Tropical Cyclones, New Delhi

S No.	Maximum sustained surface wind Speed in knot (kmph)	Nomenclature
1.	Less than 17 (< 31)	Low Pressure Area (L)
2.	17 to 27 (31-49)	Depression (D)
3.	28 to 33 (50- 61)	Deep Depression (DD)
4.	34 to 47 (62 –88)	Cyclonic storm (CS)
5.	48 to 63 (89 – 117)	Severe Cyclonic Storm (SCS)
6.	64 to 89 (118 –166)	Very Severe Cyclonic Storm (VSCS)
	90-119 (167-221)	Extremely Severe Cyclonic Storm (ESCS)
7.	120 and above (≥ 222)	Super Cyclonic Storm (SuCS)

The second part of Chapter II contains a brief report on tropical cyclones affecting Panel countries during 2015. Based on the real time and climatological data available with India Meteorological Department (IMD), India, special features of the 2015 tropical cyclone season are highlighted. It also contains realized weather and the damages caused due to cyclones. All units used in the chapters are as per standard norms.

In the context of Chapter II, sustained winds refer to wind speeds averaged over a period of 3 minutes. Kilometer per hour (kmph) / knot is the unit used for wind speed as well as speed of movement of tropical cyclones. The S.I. unit of hecta-Pascal (hPa) is used for atmospheric pressure. Reference time used is primarily in Universal Time Coordinate (UTC). Wherever possible, station names contained in WMO Weather Reporting-Observing Stations (WMO/OMM-No.9 Volume A) are used for geographical reference with code.

Chapter III consists of contributed articles / research papers on tropical cyclones received from Member countries and scientists from various organizations.

Chapter IV contains outlines of Activities of PTC Secretariat during the Inter-sessional Period 2015-2016

CHAPTER-I

WMO/ESCAP PANEL ACTIVITIES IN 2015

1.1 METEOROLOGICAL ACTIVITIES

Activities of member countries on WMO/ESCAP Panel, WMO and UN-ESCAP for the year 2015 were presented at the forty third session of the WMO/ESCAP Panel on tropical cyclones held at New Delhi, India from 2-6 May 2016. Under this item, matters relating to the basic observational network, the telecommunication links and data-processing systems established in the region to fulfill the requirements of WMO's World Weather Watch Programme were reviewed. The Panel reviewed the activities under the meteorological component of the Members during the past year. These are briefly summarized below:

1.1.1. WMO activities

1.1.1.1. Indian Ocean Data Coverage (IODC)- CGMS Roadmap

At their 43rd session in 2015, the Coordination Group for Meteorological Satellites (CGMS) approved a roadmap for the future provision of Indian Ocean Data Coverage (satellite services) once the EUMETSAT Meteosat-7 reaches its end-of-life in March 2017 with there-orbiting of the satellite to follow in April/May 2017.

The aim of the road map is to provide a resilient multi-partner IODC service in the region. It includes the EUMETSAT best effort contribution to the overall IODC services, which includes the proposal to relocate Meteosat-8 at40°E.

1.1.1.1.1.Background

Indian Ocean Data Coverage (IODC) by EUMETSAT is a best effort undertaking which reflects a decision of the EUMETSAT Council to use a residual Meteosat First Generation capacity for this purpose, in the context of a temporary data gap over the Indian Ocean.

Meteosat-7, the last satellite of the Meteosat First Generation, will reach its end-of-life in March 2017 with the re-orbiting of the satellite to follow in April/May 2017,thereby ending the agreed best-effort support to IODC by EUMETSAT.

The paper starts by presenting the current IODC services and the agreed requirements for future IODC services.

Then, the capabilities of the CGMS partner's satellites and services in the region that may be available in 2017 and beyond are presented, followed by a detailed assessment of each system.This detailed assessment considers:

- Image acquisition schedule and scan pattern;
- Instrument performance;
- Image and product data access and redistribution;
- Product formats;
- Data Collection Systems.

The information is based on inputs received during the Intercessional period.

1.1.1.1.2. CURRENT IODC SERVICE AND REQUIREMENTS

1.1.1.1.2.1. Meteosat-7 IODC Services

Meteosat-7 was launched on 2 September 1997 and has been providing Indian Ocean Data Coverage (IODC) service at 57.5°E since 5 December 2006. The end-of-life of the spacecraft is in April 2017 with there-orbiting in May 2017.

Meteosat-7 provides several services in the region:

1.1.1.1.2.2. Imaging

- Meteosat-7 takes a full Earth disc image in three spectral channels (Visible(VIS), Infra-Red (IR) and Water Vapour (WV)) every 30 minutes;
- The pixel resolution at the sub-satellite point is: 2.5 km VIS (using both VIS detectors);5.0 km IR and WV.

1.1.1.1.2.3. Products

- The main meteorological products generated in Near-Real-Time (NRT) are Atmospheric Motion Vectors (AMV), Upper-Tropospheric humidity (UTH), Clear-Sky Radiances (CSR), All-Sky Radiances (ASR), Multi-sensor Precipitation Estimate (MPE), Cloud Analysis (CLA) and Cloud Mask (CLM);
- Of these, the AMV and CSR are currently assimilated by several numerical prediction centres operationally and the quality is monitored on an operational basis by the NWP SAF and early studies, performed by ECMWF, demonstrated the benefits of this data for their model;
- In addition, EUMET SAT IODC service supports other international activities like SCOPE-CM and is also the prime source of geostationary data in this region supporting also ISCCP (International Satellite Cloud Climatology Project).

1.1.1.1.2.4. Data Collection Systems

- 5 Indian Ocean Tsunami Warning Systems (IOTWS) networks are supported (Indonesia 12, Maldives 3, Burma 2, SriLanka 1 and Philippines 3)–21 DCPs in total;
- Hydrology/Metstations – 129 stations: Sri Lanka 122 and Bhutan 5 – 127 DCPs in total;
- Capability for HRDCPs (1200bps) has been added to the Meteosat - 7 system, but no DCPs allocated yet.

1.1.1.1.2.5. Dissemination

- Images, Products and DCP messages are variously disseminated on EUMETCast to Europe and Africa and Americas;
- Distribution of data also directly to NOAA;
- DCP bulletins disseminated on the GTS.

1.1.1.1.3. IODC User Requirements

The following user requirements for the IODC services were agreed at CGMS-42:

1.1.1.1.3.1. Imaging

- Coverage: Full Earth
- Bands: (Visible(VIS), Infra-Red (IR) and Water Vapour (WV)
- Resolution: 2.5km VIS (using both VIS detectors); 5.0 km IR and WV
- Repetition rate: every 30 minutes

1.1.1.1.3.2. Product

- Atmospheric Motion Vectors (AMV)

- Clear-Sky Radiances (CSR)

1.1.1.1.3.3. Image and Product Data Distribution

- NRT Data Distribution of L1.5 images and L2 Products

1.1.1.1.3.4. Image and Product Data Policy

- Complies with WMO Resolution 40 (Cg-XII)

1.1.1.1.3.5. DCS

- Access (Data Policy): Free for environmental use
- Data Rates(Capacity):100bps
- Data distribution: NRT via GTS and Internet

1.1.1.1.4. SATELLITE OPERATORS IN THE INDIAN OCEAN REGION

The following tables list the satellites which are and may be in operations in the Indian Ocean region (defined by CGMS as 36°E–108°E) in the time frame 2014–2017 and beyond.

Satellite	Longitude	Operator	Launch date	Projected EOL
Meteosat-7	57.5°E	EUMETSAT	02/09/1997	Q12017
Meteosat-8	3.5°E#	EUMETSAT	28/08/2002	2020
Elektro-LN1	76°E	Roshydromet	20/01/2011	≥2021
INSAT-3A	93.5°E	ISRO	04/10/2003	≥2015
INSAT-3D	123.5°E	ISRO	25/07/2013	≥2021
FY-2D	86.5°E	CMA	15/11/2006	≥2015
FY-2E	86.5°E	CMA	19/10/2004	≥2017
FY-2G	105°E	CMA	30/12/2014	≥2018
FY-2F	112.5E	CMA	13/01/2012	≥ 2018

#Potential relocation from 3.5°E to 40°E, subject to decision of the EUMETSAT Council after the successful commissioning of FY2-G:

* FY-2E has been relocated from 105°E to 86.5°E

** FY-2G has been relocated from 99.5°E to 105.5°E

Note: for completeness FY-2F is located at 112.5°E.

1.1.1.1.5. Future Satellites

Satellite	Longitude	Operator	Launch date	Projected EOL
Elektro-LN2	77.8°E	Roshydromet	≥2015	≥2022
INSAT-3DR (Repeat)	74°E	ISRO	≥2015	≥2023
INSAT-3DS (Spare)	74°E	ISRO	≥2022	≥2029
FY-2H	86.5°E (TBC)	CMA	≥2016	≥2020
FY-4A	86.5°E (TBC)	CMA	≥2016	≥2022
FY-4B	105°E(TBC)	CMA	≥2018	≥2022
FY-4C	86.5°E (TBC)	CMA	≥2020	≥2022

All data taken from:http://www.wmo.int/pages/prog/sat/satellitestatus.php

ASSESSMENT BY EUMETSAT OF POTENTIAL CONTRIBUTIONS TO IODC SERVICES FROM PARTNERS

1.1.1.1.5.1. Roshydromet

1.1.1.1.5.1.1. Images and Products

The ROSHYDROMET's Elektro-LN1 system is located around 20 degrees further east than Meteosat-7, at 76°E with both space and ground segments in place. Elektro-LN1 provides full disk imagery at 30 minute intervals in 10 infrared and visible channels at a resolution of 4km (IR channels) and 1km (VIS channel), however, the overall performance of the satellite images and product in terms of quality, availability and timeliness is that of an experimental satellite, and not comparable to Meteosat-7.

Sample level 1.5 HRIT image files have been made available to EUMETSAT by ROSHYDROMET– these have also been made available to Member State's NMSs. An initial analysis of the image channels shows that some channels are badly affected by noise, also confirmed by ROSHYDROMET. No higher level products are available operationally and they are also not monitored by global NWP centers or the EUMETSAT NWP SAF(Satellite Application Facility).

Atrial Elektro-LHRIT service on EUMETCast was started in August 2011 to allow an evaluation of the usefulness of the data to be made by EUMETSAT Member States; however at the time of writing, Elektro L N1 data is only intermittently available due to an ongoing satellite anomaly.

The second satellite in the Elektro-L series (N2) has been launched on 11 December 2015 and is currently undergoing commissioning. More details at http://www.wmo-sat.info/oscar/satellites/view/74 .

1.1.1.1.5.1.2. Data Collection Services

The DCS is fully functional using Elektro-LN1. Roshydromet is ready to provide WMO members with the international channels for data transmission from DCPs via Electro-LN1 if required.

Information concerning how to allocate DCPs and how to access DCP data outside Russia is not yet available. It should be noted that DCP messages are not currently distributed on the GTS. ROSHYDROMET has indicated its willingness in adding the data on the GTS should it be required.

1.1.1.1.5.2. ISRO

1.1.1.1.5.2.1. Images and Products

INSAT 3D at 82°E was launched in July 2013. Sample images and also sample L1b data (counts, radiances, temperatures, albedos, SST) have been made available to EUMETSAT for assessment. The preliminary results are very favorable. The L1B data are well laid out in HDF and easy to read with good metadata, with full explicit geo- location, the data size is about 420 MB per image cycle. Additionally L1C data are available~90MB in HDF5, with projection details (50N to 50S, 20E to 150E). The SST is also in HDF and covers the Indian Ocean, the Arabian Gulf, the South China Sea, etc. INSAT-3D AMVs are available on the GTS.

Off-line AMV passive monitoring at ECMWF was introduced from October 2014, and there are plans to include this in the operational monitoring. ECMWF state that AMV quality looks promising. The monitoring statistics are generally in line with what is seen for other GEO satellites. Some open issues remain, which have been passed to IMD.

There are some issues with the provision of the data that should be solved before actual use of the data can be considered:

- Provide more meaningful quality control information;
- Separate cloudy and clear-sky water vapour AMVs;
- Use correct computational method in the BUFR file;
- Understand why and when a limit of 1000 observations/channel/time is applied.

1.1.1.1.5.2.2. Data Collection Services

Information concerning the Data Collection Service operated by ISRO is presented in Annex II. INSAT3A currently supports the DCS. ISRO have agreed to the possible use of the INSAT DCS by WMO members if required, however it should be noted that the ISRO System does not support 100bps DCPs, which transmit via Meteosat-7.

1.1.1.1.5.3. CMA

1.1.1.1.5.3.1. Images and Products

The FY-2D and 2E satellites currently provide full disk images every half an hour in five channels (Vis at 1.24 km all infrared (IR), shortwave IR, water vapour and two split window at 5km).These images are received at EUMETSAT and disseminated via EUMET Cast.

For FY-2E located at 105°E, coverage of the Indian Ocean region is not comparable to that provided by Meteosat-7 and not focused on the same area of interest. FY-2D at 86.5°E provides better coverage of the Indian Ocean region but is 30 degrees to the east of Meteosat-7. The flow of FY2-D and FY2-E image data and products to EUMETSAT is reliable and is simple in terms of configuration leading to a service of high availability.

The FY-2D imagery has been reported to have significant stray light problems affecting the FY-2D image and product quality. This was confirmed at bilateral meetings with CMA, where CMA also stated that the water-vapour channel spectral response function was not well characterized pre-launch. Therefore, it is not possible to generate clear-sky radiance products from this satellite. The water-vapour channel issues, combined with the stray light effects have rendered the FY-2DAMVs unusable for global NWP data assimilation.

These observations are in line with the results of the EUMETSAT NWP SAF and global NWP centres satellite-derived wind-speed and radiance product monitoring. This site shows the results of product comparisons routinely generated for any satellite operator that makes the products available to the global community.

The following URL provides a link to the NWP SAF AMV monitoring as well as to the monitoring provided by some other NWP centres:

http://research.metoffice.gov.uk/research/interproj/nwpsaf/monitoring.html

CMA is planning to replace FY-2D with FY-2E, following the successful launch and commissioning of FY2-G in 2015.

1.1.1.1.5.3.2. Data Collection Services

Information concerning the Data Collection Service operated by CMA is presented in Annex II. CMA operates the DCS on FY-2E at 105°. CMA also confirmed that the international channels can be used by international users if required. The DCS would need to be operated via the satellite at 86.5°E if it were to be are place meant for the current Meteosat-7 service. Additionally further information is required concerning the allocation process and the DCP data distribution mechanisms.

Provider	Satellite Monitored	Radiances	Radiances assimilated	AMVs monitored	AMVs assimilated
CMA	FY-2D/2E	No	No	Yes	No
Roshydromet N1	Elektro-L	No	No	No	No
ISRO	INSAT-3D	No	No	Yes	No
EUMETSAT	Meteosat-7	Yes	Yes	Yes	Yes

1.1.1.1.6 Satellite product usage at ECMWF

The following table shows the usage of the data (AMV, CSR) from satellites in the region by the European Centre for Medium-Range Weather Forecasts (ECMWF).

There is no experience on the ROSHYDROMET products as Elektro-LN1 is currently not imaging. The CMA FY-2E Atmospheric Motion Vectors have been assimilated experimentally. Regarding the ISRO INSAT-3D AMVs, initial indications are that the winds are of good quality.

Regarding inter-calibration with other satellites, the Global Space based Inter-Calibration System (GSICS) is the forum where these activities are developed.

1.1.1.1.7. POSSIBLE EUMETSAT CONTRIBUTION TO CONTINUATION OF IODC SERVICES

Based on the EUMETSAT analysis of the CGMS partners' capacities presented in section 4 and on bilateral discussions held with international partners, EUMETSAT presented a possible scenario for the continuation of the IODC services beyond 2016 to its Council in November 2014. This scenario would be to rely in the future on the operational capability provided by ISRO (INSAT-3D at 82°E and INSAT-3DR/D Sat 74°E) and by CMA (FY-2E and

Follow – on at 86.5°E). Such a constellation would become available by the end of 2015, once FY-2E has been repositioned at 86.5°E. Once Elektro-LN2 is launched and successfully commissioned, this could also be added to the overall constellation.

In addition, in the 2016 time frame, Meteosat-8 might be repositioned around 40°E, to support the acquisition of images in the Western part of the Indian Ocean. This intermediate position would overlap with other satellites, maximizing opportunities of cross-calibration, and increasing the robustness/resilience of the IODC mission thanks to international cooperation.

Should Meteosat-8 be relocated to 40°E, then the DCS, currently using Meteosat-7 could easily be moved to Meteosat-8.

The EUMETSAT Council agreed that EUMETSAT further study the relocation of Meteosat-8 to 40°E, with the understanding that the remaining Meteosat satellites are capable of supporting the EUMETSAT Baseline operational services. In the nominal MSG-4 schedule, such a decision by the EUMETSAT Council can be expected in June 2016.

1.1.1.1.8. PROPOSED CGMS IODC SCENARIO AND TIME LINE

Based on the above, EUMETSAT is proposing to CGMS a scenario and a time line for IODC services after 2016 with associated actions. This scenario is proposed for endorsement under the following assumptions.

Assumptions:

- FY2-G is successfully commissioned in 2015
- MSG-4 is successfully launched and commissioned in 2015 (N.B. T his assumption has been fulfilled with the successful commissioning of MSG-4 on 16 Dec 2016, as Meteosat-11)
- EUMETSAT Council approves the relocation of Meteosat-8 to 40° E in 2016
- Elektro-LN2 is successfully launched and commissioned in 2015

Proposed scenario

Satellite	Location	Image	Products	DCS
Meteosat-8	40°E	Yes	Yes	Yes (International)
INSAT 3D	74°E	Yes	Yes	Yes (regional)
Elektro-LN2	77.8°E	Yes	Yes	Yes (regional)
FY2-E	86.5°E	Yes	Yes	Yes (regional)

Dissemination of CGMS Satellite data and products via EUMET Cast and the GTS. Further Meteosat-8 data access mechanisms for CGMS partners will be discussed during the WGIII meeting.

Proposed time line

2015

- EUMETSAT to disseminate INSAT-3D images and products via EUMET Cast
- CMA to relocate FY2-E to 86.5°E and commence an operational service
- EUMETSAT to disseminate FY2-E images and products from 86.5°E via EUMET Cast

2016

- EUMETSAT relocate Meteosat - 8 to 40°E
- EUMETSAT commence Meteosat-8 operational service including images and products via EUMET Cast
- Roshydromet commence an Elektro-L N2 operational service
- EUMETSAT to disseminat eElektro-L N2 images and products via EUMET Cast

1.1.1.2. OBSERVING SYSTEMS

1.1.1.2.1. REGIONAL BASIC SYNOPTIC NETWORK (RBSN)

The Integrated WWW Monitoring (IWM) and the Annual Global Monitoring (AGM)1 continued

See detailed monitoring results in http://www.wmo.int/pages/prog/www/ois/monitor/index_en.html to provide information on the performance level of the observing and telecommunication systems. As per the results of the AGM exercise carried out in October 2015, the availability of expected SYNOP and TEMP reports on the Main Telecommunication Network (MTN) from a total of 298 surface and 54 upper-air stations in the RBSN operated by Members of the WMO/ESCAP Panel on Tropical Cyclones are provided in the table below.

Except for one country, the availability of SYNOP reports continued to be more than 75% for all countries while the average availability ranged from 50% to 100% during the inter-sessional period. Overall, the total availability of SYNOP reports increased to 95% from 91% in the previous year.

The average availability of TEMP reports ranged from zero to 72% in 2015 with increased availability in most countries. Compare to the previous year, the availability of TEMP reports from Sri Lanka remained at zero percent, while the availability for Myanmar decreased from 6% to zero percent during the current period. Overall, with the positive increase in the number of reports received from a majority of Panel Members the total availability of TEMP reports increased from 23% to 40% during the intersessional period.

Availability of SYNOP and TEMP reports from RBSN stations (source: AGM-IWM-SMM)

Annual Global Monitoring: 1-15 October 2014/2014

Country	Number of stations / Reports received (%)							
	Surface (SYNOP)				Upper-Air (TEMP)			
	(10/2014)		(10/2015)		(10/2015)		(10/2015)	
Bangladesh	12	85%	12	92%	3	36%	3	40%
India	81	94%	81	100%	34	23%	34	47%
Maldives	5	100%	5	100%	1	0%	1	43%
Myanmar	27	45%	27	50%	5	6%	5	0%
Oman	23	82%	23	97%	2	42%	2	72%
Pakistan	54	100%	54	100%	3	33%	3	57%
Sri Lanka	9	97%	9	94%	1	0%	1	0%
Thailand	87	100%	87	100%	5	26%	5	20%
Total	**298**	91%	**298**	95%	**54**	23%	**54**	40%

Investigations into dissemination of especially upper-air data indicate that some countries continue to perform observations at non standard times of observations[2] resulting in the

See: http://library.wmo.int/pmb_ged/wmo_544-v2-2011_en.pdf possible non inclusion of availability in the Annual Global Monitoring (AGM) results. The four main standard times of observations for surface synoptic stations are 00, 06, 12 and 18 UTC and for upper-air synoptic stations carrying out radiosonde and radiowind observations it is 00 and 12 UTC.

1.1.1.2.2. MARINE AND OCEAN METEOROLOGICAL OBSERVATIONS

The Observations Programme Area (OPA) of the Joint WMO-IC Technical Commission for Oceanography and Marine Meteorology (JCOMM), in 2015 developed a five year work plan (2015-2020), taking into considerations of observational requirements, observing systems performance monitoring, risk assessment etc. The observing system is proposed to meet both climate requirements, and the requirements of non-climate applications, including NWP, tropical cyclone prediction, global and coastal ocean prediction, and ocean forecasting and marine services in general. Detailed requirements are documented in the Implementation Plan of the Global Climate Observing System update (GCOS No.184[3]).

In the past years, there has been some progress in the marine observing networks at global and regional levels. The observing system met 66% its global implementation targets by December 2015, a slight increase from last reporting period. All data are made freely available to all Members in real time. There are several observing networks that fully meet their implementation goals, such as surface measurements from Voluntary Ships (VOS), global drifting surface buoys, Argo profiling floats 100% completion[4]. The progress results from investment and efforts from Members/Member States, including in the WMO Regional Association II (RA-II), while sustainable investment is still needed to maintain and implement the observing systems target.

The global surface buoy network coordinated through the Data Buoy Cooperation Panel (DBCP) has now been sustained and stable (historical target of 1,250 drifters operational). The Implementation Plan of the Global Climate Observing System (2010) required to increase number of drifters carrying pressure sensors, and 57% operational drifters currently available for sea level pressure. The Seventeenth Session of WMO Congress (Cg-17, May-June, 2015, Geneva, Switzerland) urged Members to follow DBCP recommendations on vandalism prevention. Cg-17 also invited all Members to commit appropriate resources to the barometer drifters, and the tropical moored buoy arrays, with a view to support Members improving NWP. New technologies such as surface gliders also have the potential for contributing useful data to typhoon prediction.

A series of training workshop have been organized by DBCP for the North Pacific Ocean and its Marginal Seas (NPOMS). These workshops focus on the application of regional ocean observations for increasing society's understanding and forecasting of typhoons in the NPOMS region. Based on lessons and experience obtained over the past 4 NPOMS workshop, Members are encouraged to comply with existing data policies of WMO and IOC, and to share data real time via GTS. Members are also encouraged to engage and use the WMO Rolling Review of Requirements, and consider the requirements for ocean observations in support of Typhoon prediction. NPOMS-4 (Rep. of Korea, November 2015) raised the question of the importance of stratification in the NPOMS region to TC development. NPOMS-4 agreed that to answer this question, more strategic observations are required, to include upper ocean heat content. Observations can also help assessing the

[3] http://www.wmo.int/pages/prog/gcos/Publications/gcos-184_I.pdf

[4] http://www.osmc.noaa.gov/images/JCOMM_cartoon.pdf

impact of warm and cold eddies on intensification of typhoons. Impact of data should be assessed e.g. through Observing Systems Experiments (OSEs), hindcast sensitivity studies, and efforts made to assimilate more of existing impactful data. In the meantime, Members are encouraged to engage with the Commission for Basic Systems (CBS), the Tropical Cyclone Programme, and the JCOMM Expert Team on Operational Ocean Forecasting System (ETOOFS) to take informed and coordinated actions on typhoon observations and forecasting.

As reported before, Argo profiling float programme reached completion in November 2007, and about 90% of Argo profiles are distributed electronically within 24 hours of acquisition, efforts to reduce delays in the Global Data Acquisition Centres (GDACs) data distribution are increasing their timeliness. In 2015, about 800 floats were deployed, with several deep Argo floats tested, and a growing number of Bio-Argo floats. This added up to 3846 floats operational in mid-April 2016. Argo floats are continuously providing essential upper ocean thermal and salinity data for Tropical Cyclones research, monitoring and forecast activities. This also makes it possible to map detailed structure of global ocean temperature and salinity fields at both surface and subsurface levels. However, with the current deployment rate, it has been demonstrated (see study[5], *Durack et al.*, 2016) that the level of reporting profiles could not be sustainable in the long term, and the Argo array would decline over the next decade to about 2400 floats.

The Global Sea Level Observing System (GLOSS) continues to provide tide gauge data for understanding the recent history of global sea level rise and for studies of interannual to multi-decadal variability. In the meantime, tide gauges are now playing a greater role in regional tsunami warning systems and for operational storm surge monitoring. Over 88% of the GLOSS Core Network (GCN) of about 290 stations can be considered operational. GLOSS now plans to expand high quality core network beyond initial slate of stations to meet higher level of standards.

In addition, JCOMM Observations Programme Area (OPA) also coordinates the Ship Observations Team[6] (SOT), including the Voluntary Observing Ship scheme (VOS, for the making of marine meteorological observations), the Ship of Opportunity Programme (SOOP, for the making of oceanographic observations, including upper ocean thermal profiles), and the Automated Ship Board Aerological Programme (ASAP, for the making of upper air observations). The SOOP programme is providing useful upper ocean thermal profile data in complement of similar data from the Argo profiling float programme, and the Global Tropical Moored Buoy Array. Such data are essential for providing estimates of heat content fluxes between the ocean and the atmosphere in support of typhoon prediction.

The Panel is invited to consider sustained and enhanced contributions of WMO Members in the region in support of the implementation of the ocean observing systems, including buoy, Argo, and ship-based networks in the tropical oceans and the provision of ship time to assist in the deployment and servicing of tropical moored buoys, and for the deployment of drifters and XBTs. Members interested to contribute are invited to contact the Technical Coordinator of the Data Buoy Cooperation Panel (DBCP), Ms Champika Gallage (support@jcommops.org and cgallage@jcommops.org).

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[5] http://www.nature.com/nclimate/journal/v6/n3/full/nclimate2946.html?WT.feed_name=subjects_hydrology

[6] http://www.wmo.int/pages/prog/amp/mmop/sot.html

1.1.1.2.3. AIRCRAFT-BASED OBSERVATIONS

The WMO Aircraft Based Observing System, comprising the Aircraft Meteorological Data Relay (AMDAR) observing system[7]supplemented by aircraft based observations (ABO) derived from ICAO systems, now produces around 700,000 upper air observations per day on the WMO GTS, with the AMDAR system contributing the vast majority from 40 participating airlines and a global fleet of over 4000 aircraft. This important sub-system of the WMO Integrated Global Observing System produces both en-route and vertical profile (from AMDAR aircraft at airport locations) high quality, upper air data, that continues to demonstrate a significant positive impact[8] on global, regional and high resolution NWP and other forecasting and meteorological applications.

While the WMO AMDAR programme has continued to grow, as demonstrated in Figure 1 below, there has been no growth in the programme in recent years in WMO Region II and V (Asia and Southwest Pacific).

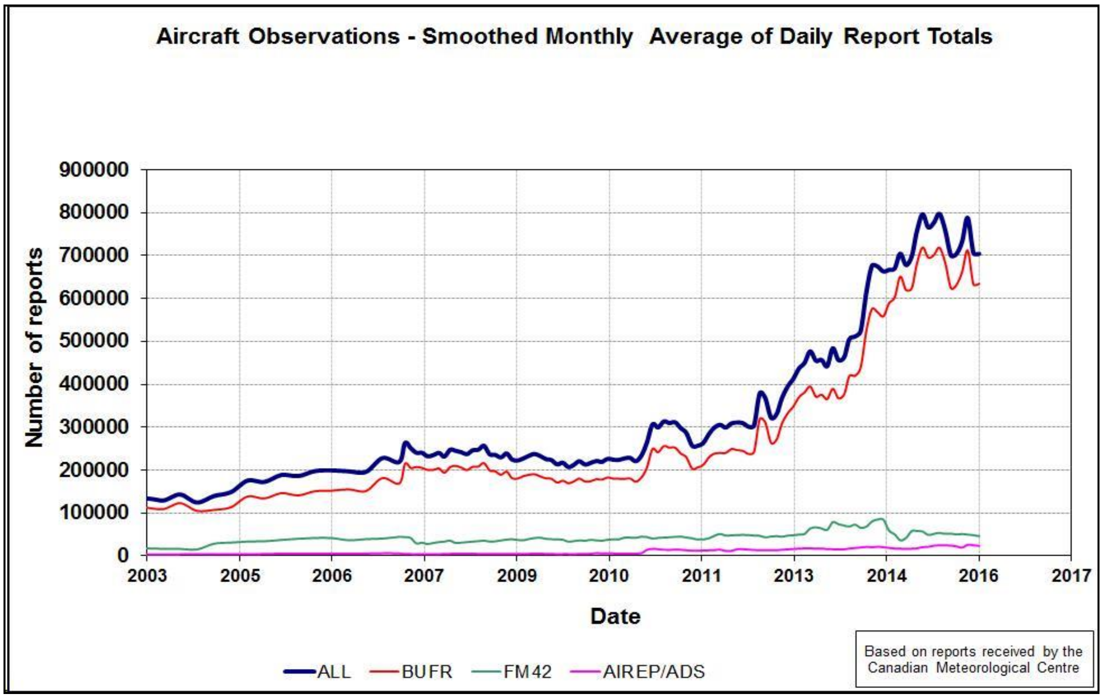

Figure 1: Average daily aircraft based observations available on the WMO GTS.

Additionally, there remain large gaps in ABO/AMDAR over Central Asia and the tropical Southwest Pacific, as can be seen in Figure 2, which provides an indication of the coverage over a recent 24-hour period.

This is despite the fact that there is ample potential for new development that would contribute strongly to improved upper air observations coverage over this region and, as a result, improved forecast skill and benefit to severe weather applications.

In line with a WMO Congress decision, the WMO Commission for Basic Systems (CBS) through its relevant work teams is currently working with WMO Regional Associations (RAs) to develop ABO and AMDAR strategy and implementation plans for each WMO region. This activity will be based in part on the results of a WMO study on airline capabilities for

[7] http://www.wmo.int/pages/prog/www/GOS/ABO/AMDAR/index_en.html

[8] See : http://www.wmo.int/pages/prog/www/GOS/ABO/data/ABO_Benefits.html

future AMDAR participation[9], which has identified the key target airlines that might contribute to AMDAR data coverage improvement over this region. The study identified 42 airlines with over 1500 aircraft capable of contributing to the AMDAR programme over the Middle East, Central Asia and the Southwest Pacific. The meeting might like to consider how support might be given to the relevant WMO RAs so as to encourage and foster further AMDAR programme development in the region, in the interests of improved monitoring and forecasting of regional severe weather systems.

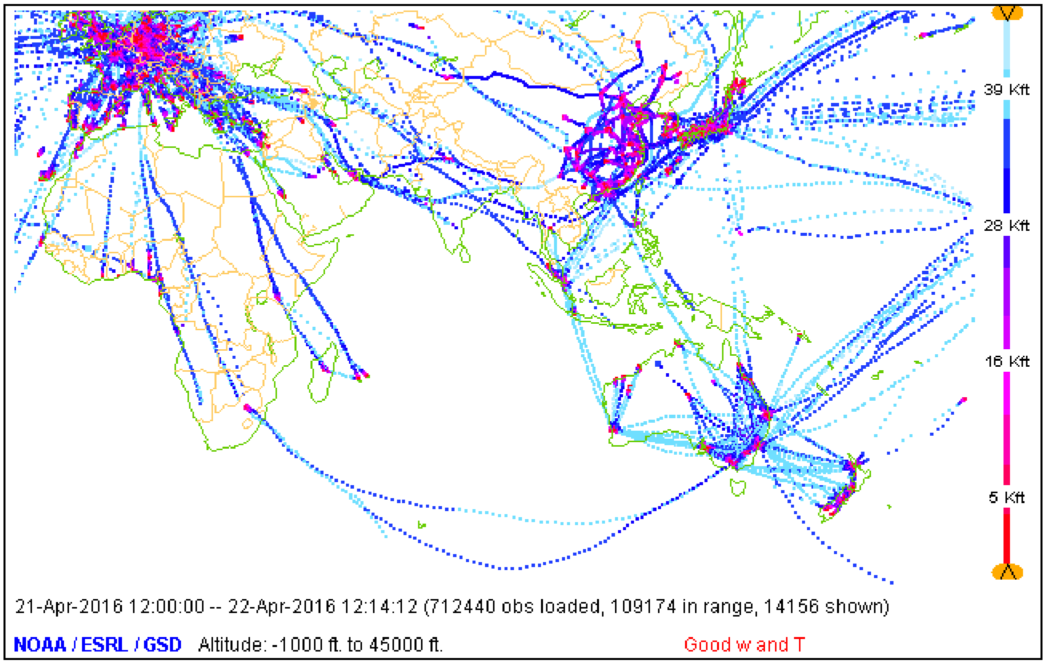

Figure 2: 24-hour aircraft based observations data coverage over Asia and the Southwest Pacific. Low-level red-coloured dots indicate locations where vertical profiles are produced.

1.1.1.2.4. SURFACE-BASED REMOTELY-SENSED OBSERVATIONS

Of critical importance for severe weather and tropical cyclone monitoring and prediction are weather radar systems and the data and products derived from them. WMO and the Commission for Basic Systems (CBS) in partnership with the the Turkish State Meteorological Service (TSMS) have continued to maintain the WMO Weather Radar Database (WRD) (http://wrd.mgm.gov.tr/default.aspx?l=en). The database now contains metadata for over 900 weather radar systems operated by 88 WMO member countries. This database is making an important contribution to the WIGOS Information Resource and the WMO Information System as a source of radar metadata and will be used in the near future to seed and maintain the OSCAR/Surface system, which will become the repository for the metadata of all stations that contribute to WIGOS. WMO encourages its Members to continue to nominate WMO radar metadata focal points to ensure that all weather radars are included and routinely maintained and updated in the WRD.

Further in relation to weather radar systems, WMO and its technical commissions,

[9] http://www.wmo.int/pages/prog/www/GOS/ABO/AMDAR/resources/AMDAR_Coverage_Recruitment_Study.html

CBS and the Commission for Instruments and Methods of Observation (CIMO) are working to strengthen the international coordination and standardisation of weather radar systems through a range of initiatives and activities in relation to data processing and quality control and international data exchange. In particular, the CBS Task Team on Weather Radar Data Exchange will meet again in the second half of 2016 and expects to significantly advance progress towards a WMO standard for radar data exchange. Also in 2016, work toward finalisation of the results of the CIMO Radar Quality Control and Quantitative Precipitation Inter comparison (RQQI) is expected to be advanced. Additionally, WMO has recently (2015) formed an agreement with EUMETNET for cooperation on international weather radar activities. As a global leader in regional weather radar data exchange, demonstrated through establishment and advancement of its successful OPERA program, EUMETNET is ideally placed to collaborate with WMO to assist in meeting the aim to increase international exchange of weather radar data.

1.1.1.3.WMO Information System (WIS)

The global component of the WMO Information System (WIS) is now operational. The focus of WIS implementation has now moved to the national level and is being guided by Regional Associations. Information on WIS implementation in RA II is available online at http://wis.wmo.int/page=RA2-WIS. This page has a link to the RA II WIS implementation plan (http://wis.wmo.int/file=653) adopted by the Fifteenth Session of Region Association II in December 2012, as well as a list of National WIS focal points. The team has good expert participation under the leadership of Ms Li Xiang from China and Mr Kenji Tsunodo from Japan.

Implementation of WIS should lead to significant benefits to Tropical Cyclone warning services in the Bay of Bengal and the Arabian Sea. Global Information System Centres (GISCs) supporting countries in the area include Beijing, Jeddah, New Delhi, Tehran and Tokyo. It is expected that these GISCs will work together coordinated by GISC New Delhi as the principal GISC for New Delhi Tropical Cyclone RSMC.

The WMO Global Telecommunications System (GTS) is a core component of WIS and comprises a dedicated network of surface-based and satellite-based telecommunication links and centres operated by countries, interconnecting all NMHSs for the round-the-clock rapid and reliable collection and distribution of all meteorological and related data and forecasts between NMHS. It is noted that some countries such as Myanmar do not have a registered GTS link.

Support to NMHS on how to implement and benefit from WIS is available through the Manual on WIS (WMO No. 1060) (http://wis.wmo.int/WIS-manual) and the Guide to WIS (WMO No. 1061) (http://wis.wmo.int/WIS-guide) which now include the information on WIS competencies to better assist all Members to begin to implement the new WIS functionality.

Members are reminded that the Common Alerting Protocol (CAP, ITU Recommendation X.1303) is a content standard designed for all-hazards and all-media public alerting. CAP is used in the disaster response community for delivering information about a large variety of events, and it is suitable for the dissemination of weather, climate and water related alerts and warnings. New applications and systems based on CAP are now available that could be of benefit to TC warning services. For an example, see the Home Alarm at http://wis.wmo.int/doc=3613. CAP is supported in the virtual all hazards network within the WIS-GTS and Members are encouraged to work with their users to be able to benefit from

implementation of CAP. Furthermore, Members are encouraged to note the role of the Alerting Authorities Register and its associated benefits in ensuring online search engines and other systems place priority on information from authoritative sources.
See http://alerting.worldweather.org.

1.1.2. Bangladesh

1.1.2.1 The Government of Bangladesh is considering "The Bangladesh Weather and Climate Services Regional project" to support modernization of the Bangladesh Meteorological Department's weather, water and climate information infrastructure, strengthening both the supply of meteorological data, information and services and delivery to sectors and communities. Modernization of surface, ocean and upper air monitoring networks and ICT systems includes
(1) upgrade 35 existing synoptic stations and 200 AgMet automatic weather stations;
(2) strengthen urban resilience through the addition of 65 new automatic rain gauges (ARGs) in urban cities;
(3) install Coastal-Marine Automated Network (C-MAN) comprised of 40 new coastal marine stations to detect meteorological state parameters, wave height, wave period, and storm surge;
(4) installation of 3 buoy stations for measuring ocean temperature, current, wave dynamics, and other parameters;
(5) Strengthen BMD ICT and Data Center with computer servers and software to help store and process data, GTS upgrade to WIS and expansion of GTS/WIS bandwidth, installation of dedicated and reliable high speed internet communications.

1.1.2.2. Bangladesh will explore the possibility of RADAR data exchange on real time mode through RTH by possibly creating a VPN Link. India will make a proposal for the same.

1.1.3. India

A brief description of the observational network of IMD and types of observations collected from the network are given below:

1.1.3.1. Surface Observatories

The network of surface meteorological observatories consists of total 709 Stations. The break-up of various categories is as follows:

CATEGORY OF DEPARTMENTAL OBSERVATORIES

CLASS	RMC Delhi	RMC Chennai	RMC Kolkata	RMC Mumbai	RMC Nagpur	RMC Guwahati	*Total*
I , II (a), IV, VI & SMO (Deptt.)	57	53	32	29	17	16	204

II (b), II (c), II (d), III & IV, V, VI Io & EMO (Non Deptt.)	106	71	47	30	47	25	326
V (Non Deptt. HMO)	64	17	54	21	12	11	179
TOTAL	227	141	133	80	76	52	709

1.1.3.1.1. High Wind Speed Recorders (HWSRs)

(a) Real time HWSR data through GPRS modules is available on www.imdaws.com site for the stations:Goa, Pune, Bhuj, NaliyaDwarka, Veraval, Karaikal, Kakinada, Gopalpur, Visakhapatnam, Machilipatnam, Chennai , Digha, Haldia, Sagar Island, Kalingapatanam, Balasore,Paradip, Puri and Nellore

The on-line data will be made available on www.imdaws.com site shortly for above four stations.

1.1.3.2.Upper Air observatories

- **i.** 06 Nos. of GPS based systems (make M/s GRAW Germany) installed/ commissioned at RMCs to up-grade these RS/RW stations as per WMO GCOS Network (GUAN) standard. Action being taken for induction of these stations into GUAN network.
- **ii.** Pilot Balloon (PB) observatories of Sundernagar and Dehradun up-graded to RS/RW.
- **iii.** 13 Nos. of GPS based systems (make M/s Jinyang Korea) installed/ commissioned at RS/RW Agaratala, Siliguri, Gorakhpur, Lucknow, Ranchi, Karaikal, Machhilipatnam, Mangalore, Kochi, Jodhpur, Jammu, Sundernagar& Dehradun.
- **iv.** 7 Nos. of GPS based systems (make M/s Changfeng China) installed/ commissioned at Patiala, Gwalior, Jagdalpur, Raipur, Jaipur, Aurangabad & Bangalore to up-grade these RS/RW stations
- **v.** Total network of upper air radiosounding (RS/RW) of 39 stations has been upgraded with GPS based radiosounding, and all the stations are working at present.
- **vi.** Indigenous GPS based radiosonde is in final stage of production. Procurement of different components in different stages-production to start on receipt of material.

1.1.3.3. Meteorological Satellite

At present IMD is receiving and processing meteorological data from three Indian satellites namely Kalpana-1, INSAT-3A & INSAT-3D. Kalpana-1 was launched on 12th September, 2002 and is located at 74.0°E. INSAT-3A was launched on 10 April, 2003 and is located at 93.5°E. INSAT-3D was launched on 26 July 2013. Kalpana-1 and INSAT-3A both have payload of Very High Resolution Radiometer (VHRR) for imaging the earth in three channels viz. Visible (0.55-0.75 μm), Infra-Red (10.5-12.5μm) and Water vapour (5.7-

7.1µm) having resolution of 2X2 km in visible and 8X8 km in Water vapour (WV) and Infra-red (IR) channels. In addition, the INSAT-3A has a three channel Charge Coupled Device (CCD) payload for imaging the earth in Visible (0.62- 0.69um), Near IR (0.77-0.86µm) and Short Wave IR (1.55-1.77µm) bands of Spectrum.
The Resolution of CCD payload in all the three short wave (SW) channels is 1KmX 1 Km. INSAT-3D has an advanced imager with six imagery channels **{**Visible (0.55-0.75 µm), Short wave Infra-Red (SWIR) (1.55-1.70 µm), Medium Infra-Red (MIR) (3.80-4.00 µm), Thermal Infra-Red-1(TIR-1) (10.2-11.3 µm), TIR-2 (11.5-12.5 µm), & WV (6.50-7.10 µm)**}** and a nineteen channel sounder (18 IR & 1 Visible) for derivation of atmospheric temperature and moisture profiles. It provides 1 km. resolution imagery in visible band, 4 km resolution in IR band and 8 km in WV channel.

At Present about 48 nos. of satellite images are taken daily from Kalpana-1, approximately 20 images are taken from INSAT-3A. Imaging from CCD is done 5 times during daytime only. Half hourly satellite imageries are also obtained from all the six imager channels and hourly images from the sounder channels of INSAT-3D satellite. All the received data from the satellite are processed and archived in National Satellite Data Center (NSDC), New Delhi. INSAT-3D Meteorological Data Processing System (IMDPS) is processing meteorological data from INSAT VHRR and CCD data and supports all operational activities of the Satellite Meteorology Division on round the clock basis. Cloud Imagery Data are processed and transmitted to forecasting offices of the IMD as well as to the other users in India and foreign countries.
The following products derived from the satellite are useful for monitoring of tropical cyclones

1. Outgoing Long wave Radiation (OLR) at 0.250X0.250 resolution
2. Quantitative Precipitation Estimation (QPE) at 10 /10 resolution
3. Sea Surface Temperature (SST) at 10 /10 resolution
4. Cloud Motion Vector (CMV)
5. Water Vapour Wind (WVW)
6. Upper Tropospheric Humidity (UTH)
7. Temperature, Humidity profile
8. Value added parameters from sounder products
    a. Geo-potential Height
    b. Layer Precipitable Water
    c. Total Precipitable Water
    d. Lifted Index
    e. Dry Microburst Index
    f. Maximum Vertical Theta-E Differential
    g. Wind Index

At present Dvorak technique is used but manually applied. Recently efforts have been made for automation of this technique. Automated Dvorak technique version (8.2.1) is running in experimental mode at Satellite Application Unit, Satellite Meteorology Division. Satellite Application Unit is also using Microwave imageries operationally from NOAA, Metop's DMSP satellites for locating the tropical systems. Satellite Application Unit issues three hourly bulletins in general and hourly and half hourly bulletins in case of tropical cyclones and other severe weather events.

With the Web Archival System developed at IMD, KALPANA-1/INSAT-3A/INSAT-3D products & imageries are archived. The automatic script is being used to keep and update the images/products on the website for 6 months. These are available to all users.

1.1.3.4. Performance of operational NWP models for cyclone forecasting during 2015

1.1.3.4.1.NWP Division of India Meteorological Department (IMD) operationally runs three NWP models WRF (ARW), HWRF and Global model (GFS T574/L64) for short and medium range predictions (3-7 days). As a part of effort to translate research to operation, and to meet the need of the operational forecaster, IMD developed and implemented an objective NWP based Cyclone Prediction System for the operational cyclone forecasting work. The method comprises of five forecast components, namely (a) Cyclone Genesis Potential Parameter (GPP), (b) Multi-Model Ensemble (MME) technique for cyclone track prediction, (c) Cyclone intensity prediction, (d) Rapid intensification and (e) Predicting decaying intensity after the landfall.

1.1.3.4.2. Under NOAA-MoES collaboration program the basic version of the model HWRFV (3.7+) which was operational at EMC, NCEP, USA was ported on IITM ADITYA HPCS machine with nested domain of 27 km, 9 km and 3 km horizontal resolution and 61 vertical levels with outer domain covering the area of 216X432, 106X204 and innermost domain 198X354 with Center of the system adjusted to the Center of the observed cyclonic storm. The model is run on real time six hourly basis (started from cyclone season 2015) based on 00, 06, 12 and 18 UTC initial conditions to provide 6 hourly track and intensity forecasts along with surface wind and rain swaths valid up to 126 hours. The model uses IMD GFS-T574L64 analysis/forecast as first guess.

1.1.3.4.3. As part of WMO Program to provide a guidance of tropical cyclone (TC) forecasts in near real-time for the ESCAP/WMO Member Countries based on the TIGGE Cyclone XML (CXML) data, IMD implemented JMA supported software for real-time TC forecast over North Indian Ocean (NIO) during 2011. The Ensemble and deterministic forecast products from UKMO (50+1 Members), NCEP (20+1 Members), UKMO (23+1 Members) and MSC (20+1 Members) are available near real-time for NIO region for named TCs. These Products includes: Deterministic and Ensemble TC track forecasts, Strike Probability Maps, Strike probability of cities within the range of 120 kms 4 days in advance. The JMA provided software to prepare Web page to provide guidance of tropical cyclone forecasts in near real-time for the ESCAP/WMO committee Members.

1.1.3.4.4. NWP Division using Quality Controled DWR data in WDSS-II Nowcasting system and ARPS model 3D Var for very short-range forecasting. In addition, NWP Division also using these data sets in WRF model experimentaly. The same will be made operational after validation. Presently IMD operates two Nowcast Systems based on DWR data input (1) Warning Decision Support System Integrated Information (WDSSII) (updated every 10 minutes) for Metropolitan City Forecast and Aviation forecast (Single Radar Products) at Delhi, Chennai, Hyderabad and Kolkata forecast for next 2 hours (2) Advanced Regional Prediction System (ARPS) (thirty minutes updates) for NW, South, NE regions for forecast for next 9 hours.

1.1.3.4.5. INSAT 3D AMV data assimilation in GFS model and MEGHA-TROPIQUES satellite SAPHIR Radiance (6 channel) INSAT 3D Sounder Radiance (5 Channels) in WRF model initiated. DWR data assimilation in WRF model started in experimental mode.

1.1.3.4.6. Experimental dynamical extended range forecast based on multi model ensemble (MME) for 4 weeks rainfall using model outputs from IITM CFS V2 and other global centres prepared every week and made available through IMD website.

1.1.3.4.7. Experimental Monthly and seasonal global forecasts for temperature and rainfall was prepared every month and made available through IMD website.

1.1.3.4.8. Establish a state-of the-art climate data centre with advanced climate data management system with observation Quality Control as per WMO standard.

1.1.3.4.9. Increased city Forecast to 310 cites, Tourist city Forecast from 87 to 107 destinations and validity of local forecast increased from 5 to 7 days.

1.1.3.5. Telecommunication Network in IMD

Present Status of Circuits in the GTS connected with RTH, New Delhi

1.1.3.5.1. National Meteorological Telecommunication system

India Meteorological Department has its National Meteorological Telecommunication Centre (NMTC) with an Automatic Message Switching computer System (AMSS) which is connected to WMO Centers on the GTS. The existing RTH switching system "TRANSMET" is the state-of-the-art technology system. It consists of two Separate Automatic Message Switching System (AMSS) for National and International data exchange. Each AMSS works in hot standby mode for 100% redundancy in case of any failure.

During the period 2014-2015 following new data sets were received from different circuit and submitted on GTS

a. BUFR data from Pakistan
b. Storm Information, Forecast and Advisories messages from RSMC NEW Delhi in Text and Graphical form.
c. ASCII & BUFR AWS/ARG data are shared on GTS.
d. Sixteen(16) operational RADAR data are received in NETCDF and BUFR format and routed to users as per their requirement.
e. Forecast via SMS during AMARNATH Yatra gets disseminated through RTH to the users concerned.
f. Warning messages such as Tsunami and Cyclone messages received from INCOIS and RSMC are disseminated via SMS as per the user requirement.
g. INSAT-3D wind data is being shared on GTS.
h. Data received from NAVY for Porbandar station and disseminated for FDP (CTCZ).
i. RMDCN link has been upgraded to 4 Mbps RMDCN-NG(Next Gen) which handles 6 circuits viz. Tokyo, Moscow, Beijing , Germany, Exeter and Toulouse. This has improved the data exchange between these GTS centres.
j. New Delhi- Bhutan link established for Meteorological data exchange on GTS.
k. MPLS VPN link at HQ New Delhi has been upgraded to 8 Mbps for smooth catering of data requirements to the national users. This will help in faster data reception at Head Quarter from DWR stations & NWP Centres to various users.

1.1.3.5.2. VPN Circuits

Fifty four, IMD stations are connected with IPVPN connectivity speeds ranging from 256 Kbps to 8 Mbps. These VPN circuits are connected with Synergie Systems at various out stations, Doppler Weather Radar Stations, AMSS Centres and Regional Centres.

1.1.3.5.3. IVRS

Popularly known as "Weather on telephone", the Interactive Voice Response System (IVRS) is functioning with effect from July, 2000. One can access current weather and forecast for major Indian cities and air quality of some selected cities by dialing Toll free number 1800 180 1717 (List of IVRS stations enclosed as Annexure III).

1.1.3.5.4. Internet Services

At present IMD has two independent Internet leased links of 100 Mbps and 60 Mbps from different Internet service providers. IMD is also connected to 1 Gbps NKN (National Knowledge Network) link of NIC for internet, data exchange within Close User Group (CUG), Video conferencing & Telepresence services.

1.1.3.5.5. GMDSS

India has been designated as an issuing authority under the GMDSS programmefor Meteorological Area VIII (N). This covers the area of the Indian Ocean enclosed by the lines from Indo-Pakistan frontier in 23°45′N 68°E; 12°N 63°E, thence to Cape Gardafui; the east African coast south to equator, thence to 95°E to 6°N, thence to the Myanmar / Thailand frontier in 10° N 98° 30′ E.

India Meteorological Department is transmitting daily two GMDSS bulletins for Met. Area VIII(N), one at 0900 UTC and other at 1800 UTC. During Cyclone Season additional bulletins (4) are also being issued for GMDSS broadcast depending on the requirement. GMDSS bulletins are transferred to Earth Station of Tata Communication Ltd. at Pune through email as well as uploaded on IMD Website at URL *http://www.imd.gov.*in. Pune Earth Station uplinks this information to INMARSAT satellite for broadcast to all ships in Met Area VIII(N).

1.1.3.5.6. Regional Telecommunication Hub (RTH)

Regional Telecommunication Hub (RTH), New Delhi came into existence in the year 1971. It was automated and first DS- 714 Philips Computer System became operational in the year 1974. This RTH Computer was replaced by VAX- 11/ 750 Computer in 1988. In July, 2000 RTH New Delhi has installed a SUN E- 250 Computer. Now the latest system has been installed in the year 2009 by Meteo France International (MFI). This is connected to WMO Centres on the GTS. The existing RTH computer system is driven primarily by dual HP server working on the state-of-the-art distributed networking technology. The whole system has been designed to handle high speed data circuits, message exchange through web interface, SMS & Email. It has also fax interface and audio alarm. NMTC New Delhi is connected to HPCS of NCMRWF Noida, IITM Pune through NKN and the HPCS computer at Regional Specialised Meteorological Centre (RSMC) New Delhi for instantaneous transmission of global observational data and processed information received via GTS. Moreover, NWP division of IMD is utilizing the resources of IITM HPCS to run their various models for product generations through CUG link of NKN. As regards the Meteorological Telecommunication Networks within the GTS, New Delhi telecommunication center is a designated RTH located on the Main Trunk Network (MTN). The MTN is the core network of GTS. It links together three World Meteorological Centers (WMCs) and 14 other RTHs on the MTN. The Centre is also a National Meteorological Centre (NMC) for telecommunication purposes within the framework of GTS. RTH New Delhi is directly connected with Tokyo, Exeter, Offenbach, Cairo, Jeddah, Beijing, Dhaka, Bangkok, Karachi, Male, Moscow, Oman, Colombo, Melbourne, Toulouse, Katmandu and Yangoon with different protocol and speed.

Automatic Message Switching Systems (AMSS) are also operational at the major International airports of India viz. Mumbai, Delhi, Kolkata, Chennai, Nagpur and Guwahati. The circuits linking New Delhi (Palam), Mumbai, Kolkata, Chennai, Nagpur and Guwahati Airport computers with the NMTC New Delhi are working at 512 kbps speed.

1.1.3.5.7. On line Briefing System at Chennai & Delhi (Palam) has been commissioned and functional.

Under the Modernization programme of India Meteorological Department, following systems have been installed at RTH New Delhi:-

a. **Central Information Processing System (CIPS):** High end database management system having task centre to develop, test and operationalize meteorological tasks for real time generation of meteorological products.
b. **Transmet:** Automatic Message Switching System (AMSS) to receive, check and route the meteorological data and products according to WMO standards/requirements.
c. **Public Weather System (PWS):** To deliver High quality weather products and alerts to end users like print media and Television.
d. **Clisys:** Climatological data storage system with scalable management tool for effective utilization of these data.
e. **Synergie:** Decision support system for forecasters to gather, visuslize, interact and value add meteorological forecasts and products.

The Mirror RTH at Pune is functional to act as Disaster Recovery Centre (DRC) which would be able to take over all the responsibilities of RTH New Delhi in case of any catastrophe at RTH New Delhi. This will also function as WMO WIS GISC for South East Asia and cater to all data needs for Indian users and all other WMO GISC centres in real time with 24 hours cache for all data.

1.1.3.5.8. Website of IMD

Website of IMD is operational since 1st June, 2000. It contains static & dynamically updated information on all India Weather and forecasts, special monsoon report, local weather forecasts for 300 cities, satellite cloud pictures (updated every half an hour), animated satellite cloud pictures, NWP models like GFS, WRF etc. and prognostic charts, special weather warnings, tropical cyclone information and warnings, daily, weekly and monthly rainfall distribution maps, earthquake reports, etc. This also contains a lot of static information including temperature and rainfall normals over the country and a brief overview of the activities and services rendered by India Meteorological Department. This site can be accessed round the clock with the URL: http://www.imd.gov.in . The Regional Meteorological Centres have also their own websites. IMD is also providing 100 Indian city forecast on the WMO Website daily at http://worldweather.wmo.int/066/m066.htm .

IMD has also launched a new user-friendly website for the public with URL: http://www.indiaweather.gov.in

India Meteorological Department developed its own intranet website with the address http://metnet.imd.gov.in exclusively for the use of IMD officials. All employees can access this site using their login ID. This is a very useful site and all IMD officials are accessing this site all over the country for numerous applications on official matters. The list of email addresses of senior officers are available at IMD website.

1.1.3.5.9. Information Technology Cell

Considering the ever growing influence of Information Technology in day–to-day affairs of the department, IT cell carries out the following activities:-

a) Coordination of IT initiatives of the department.

b) Supervise various IT projects to be implemented.

c) Asserting the IT literacy and imparting suitable mechanisms for its improvement.

d) Development of various in-house softwares for routine activities.

Conforming to these objectives, IT Division has developed an intra - IMD Portal, which is considered as the first step towards e-governance implementation in the department.

1.1.3.5.10. Global Data Monitoring

Special Antarctica Monitoring during the period 1-15th January, 2015 and the result was uploaded to WMO. The reception of SYNOP was 97%.

1.1.3.5.11. Ongoing projects:

a. Mirror RTH and Global Information System Centre (GISC) has been installed at Pune as a part of the WMO Information System (WIS) implementation, which includes design, development, integration with existing systems like CIPS, Clisys, AMSS, HPCs. These systems act as GISC and Data Collection and Processing Centre(DCPC) with disaster recovery centre (DRC) Pune for RTH New Delhi.
   - As per guideline of WMO, RTH New Delhi applied for GISC as well as DCPC for South Asia. Upgradation of RTH New Delhi as GISC is under process
   - After installation Mirror RTH Pune, **Audit team from WMO visited RTH/GISC New Delhi at Pune and submitted their report to WMO. After acceptance of the report by WMO, the centre shall become an operational GISC.**
   - Mirror GISC is also under process.
   - All the national VPNs are under process for upgradation from 512 Kbps to 10 Mbps.

b. Up Gradation of AMSS (Automatic Message Switching Systems) at Delhi-Palam, Kolkata, Mumbai and Chennai.

c. Development of Centralized GIS Based content managed Website of IMD under process.

d. Development of Met GIS – Web based GIS Portal under process.

1.1.4. Maldives

1.1.4.1. As the location of Maldives in the Indian Ocean happens to be a data sparse area in which shifting of ITCZ and phases of MJO take place, upper air observations from both Male'(WMO # 43555) and Gan are very important to entire meteorological community in the region and globe. Maldives urge assistance from donors and Panel Members to consider rebuilding Maldives' upper air observation network.

1.1.4.2. Total of 23 Automatic Weather Stations (AWS) has been installed and only 7 are in operation. Maintenance of these have become costly.

1.1.4.3. Maldives own only one DWR while 2 or 3 are required to cover entire area.

1.1.5. Myanmar

1.1.5.1. Myanmar urges the member countries to share their expertise with financial support and give training on telecommunication, satellite and RADAR.

1.1.6. Oman

- **Synoptic Land Stations:** There are a total of 64 meteorological stations.
- **Doppler Weather Radars**: Four Dual Polarization S-Band Doppler Weather Radar.
- **Satellite reception:** The Department installed Satellite ground receiving station for intercepting High Resolution images from Polar Orbiting satellites operated by NOAA,EUMETSAT and China as well as from geostationary satellites operated by EUMETSAT .
- **Data Processing System**
  - Global Numerical Weather Prediction NWP products are received via Internet, GTS, DWD Sat. We receive products from meteorological centers including ECMWF, NOAA, UK met office and German Weather Service (DWD). DGMAN run an operational version of COSMO model (Consortium for Small-scale Modeling). COSMO is a non-Hydrostatic limited-area numerical weather prediction. WAM based wave model was established with the kind cooperation of GKSS of Germany, which covers the Arabian Sea, gulf of Oman and Arabian Gulf. WAM model run of 14km resolution and nested into 3.5km resolution and it runs on 8 processors on the PC cluster.
  - Hurricane Weather Research Forecast (HWRF) Model is run with three resolutions, 27 , 9 and 3 km. The 3km moving nest covers the event domain and tracking the tropical cyclone movement.
  - Seasonal forecast of TCs model has been implemented in Met-office since 2014. It forecasts the probability of TC activity occurrence for the next few months. Its method is based on relating TC activity and monthly SST configurations over the NIO.

1.1.7. Pakistan

- The Government of Pakistan has approved the project entitled "Establishment of Specialized Medium Range Weather Forecasting Centre (SMRFC) and Strengthening of Weather Forecasting System in the Islamic Republic of Pakistan" with the total cost of Rs. 2.5 billion under Japanese grant-in-aid assistance. Out of the toal cost, the Government of Japan share is around 97.5 %. Under this project, the Government of Japan will provide state-of-the-art technology in order to further upgrade the forecasting and early warning capabilities of PMD. Installation of high computing system (128 nodes), Weather Surveillance Radar at Islamabad and two Wind Profiler (one each at Islamabad and Multan) are part of this project.
- PMD in collaboration with RIMES organized 3rd Monsoon Forum Workshop in Islamabad on 9th June, 2015 in which stakeholders from differnet domains like DRM, climate change, academia, NGOs, electronic and print media participated. The main objective of the workshop was to get feedback from user institutions on the relevance/usability of PMD forecast products and recommendations for further improvement in generation, communication and application of these products as well as to present seasonal forecast for Pakistan for summer monsoon season 2015.
- PMD has recently upgraded its meteorological facilitates in the Gilgit-Baltistan (GB) region and has established a full fledge Regional Meteorological Centre (RMC) in the GB region for the provision of weather and climate information at the door-step of the community living in these areas as well as to service Army Aviation. For

strengthening meteorological observation network two (02) Met. Observing stations were also established in District Layyah and Kot Addu (District Muzaffargarh) in the Punjab province.

- A Memorandum of Understanding signed between National Center for Maritime Policy Research (NCMPR), Bahria University, Karachi, and Pakistan Meteorological Department (PMD) on 3rd August, 2015 for research on Meteorological and Climatic Factors in Relation to Maritime Domain and Coastal Areas of the Country. Under this MoUNCMPR and PMD will work together to conduct research in maritime and coastal domains to enhance scholarly cooperation.
- PMD in collaboration with the Centre for Language Engineering (CLE) of University of Engineering & Technology (UET), Lahore launched Pakistan-wide telephone based Weather Information Service on 13th August, 2015. Weather information of 139 districts of Pakistan is being provided by dialling the UAN number 051-111-638-638 and 10 telephone lines have been dedicated to the system at present.
- Memorandum of Understanding was signed between PMD and Qatar Meteorology Department (QMD) on 28th October, 2015 in Doha, Qatar for enhancing cooperation and coordination in the field of marine meteorological service and to support Global Maritime Distress and Safety System (GMDSS) in the Gulf Sea. The cooperation includes multiple aspects; capacity building in the field of marine meteorology, numerical weather prediction and modelling as well as to support activites related to cliamte variability and climate change research and hazardous marine related weather events with mutual exchange of scientific and technical expertise in the field. Representatives from PMD, QMD and WMO attended the MoU signing ceremony.
- PMD in connection to the implementation of Quality Management System (QMS) (ISO 9001: 2008 certification) at its Meteorological Offices located in the country, got renewed ISO certification for 17 Met. Offices in November, 2015 for another 3-years period.
- An MoU was signed between PMD and K-Electric Limited on 22nd March, 2016 for mutual collaboration on disaster prevention due to extreme climate events. This MoU is signed in context of last year's killer heatwave in Karachi that took more than 1000 precious lives. This agreement will bring PMD and K- Electric into closer collaboration to mitigate the impacts of any anomalous weather conditions in the country, particularly in Karachi city.
- In commemoration of establishment of World Meteorological Organization on 23rd March, 1950, PMD made special arrangements to celebrate the World Meteorological (WM) Day on 23rd March, 2016 at its Institute of Meteorology and Geophysics (IMG), Karachi. People from various walks of life, institutions, academia participated in this knowledge-sharing platform. Participants were briefed though various programmes and activities about the objectives of the WM Day celebration besides sensitizing them about the looming threat of climate change, its implications, weather and climate related disasters. A brochure containing the key messages from the Secretary-General WMO, Secretary (Aviation), Government of Pakistan, and PR of Pakistan with WMO; highlighting climate projections for the 21st century developed by PMD as well as mitigation and adaptation strategies in context of climate change was also distributed among all stakeholders of PMD. At the eve of WM Day, an exhibition was also arranged at IMG, Karachi in which various meteorological and seismological instruments, meteorological charts and met. products were displayed.
- PMD has been running has been running ICOsahedralNonhydrostatic model (ICON) model since March 2015. ICON is a targeting a unified modeling system for global numerical weather prediction (NWP) and climate modeling. The model is installed on

a high performance computing cluster system of 184 cores. ICON is driven by initial conditions from the GME (Global Model of DWD, Germany) which has 13km horizontal grid resolution and 40 atmospheric Levels. ICON operates twice daily for 7days forecast on 00UTC and 12UTC, at 13km horizontal resolution. Weather Research and Forecasting (WRF) modeling system also has been deployed on High Performance Cluster Computing System for operational weather forecast up to 72 Hours at a finer resolution (7km). The model is currently being used for diagnostic studies by researchers. A GTS link via ftp has also been established between China Meteorological Administration (CMA), and PMD Islamabad. NWP products of CMA's Global Spectral Model (GSM) in Grib1 format are being uploaded to our ftp server daily at 00:00, 06:00, 12:00, and 18:00 GMT. GSM has a horizontal resolution of TL639 (0.28125 deg) and is used for Short- and Medium-range forecast.

1.1.8. Sri Lanka

Strong El-Niño conditions affected the weather over the island and below normal rainfalls were received in the mid of the year and above normal rainfalls were received at the end of the year 2015.

- **Synoptic Observations:** Data reception from 22 operational stations with the two stations commenced in 2009 namely, Polonnaruwa and Moneragala (No WMO number assigned yet) was very good.
- **Automatic Weather System Network:** The automatic weather system network in Sri Lanka consisting of a total of 38 stations has two types of stations. 22 stations are equipped with sensors to measure Wind speed and direction, Temperature, Humidity, Rainfall, Pressure and Radiation while the balance 16 stations are equipped to measure Wind speed and direction, Temperature, Rainfall and Radiation. All these stations are connected to the headquarters through a satellite based communication system (VSAT manufactured by Gilat, Israel) and observations are transmitted at 10 minute intervals. The automatic weather stations are manufactured by Meisei, Japan.
- **Agro-meteorological Network:** Agro-Meteorological Network consist of stations and are based mostly at agricultural agencies. At these stations in addition to standard meteorological parameters, agriculturally important parameters such as soil temperature and evaporation are observed twice a day by observers trained by the department. Technical assistance for maintaining this network is provided by the department.
- **Raingauge Network:** The total number of stations measuring 24-hour accumulated rainfall in Sri Lanka using manual rain gauges is approximately 512. These stations are manned by voluntary observers (trained by the department. Information from most of these stations are collected on daily basis through landline telephones while the balance stations submit the information by post at the end of each month.
- **Automated Raingauge Network:** A network of 20 automated rain gauges have been installed in areas prone to exceptionally heavy rain events, particularly in the central highlands of Sri Lanka. Observations performed automatically at these stations are received every 30 minutes at the NMEWC.
- **Upper Air Network:** Upper atmospheric wind observations are made at 04 synoptic meteorological stations (Colombo, Trincomalee, Hambantota and Mannar) at 00, 06 and 12 hrs. UTC through Balloon Theodolites. The only GPS-based Radiosonde (Make: Meisei, Japan) station in Sri Lanka is at Colombo headquarters.
- **Meteorological Satellites:** The satellite imageries through satellite receiving system of CMACast was utilized the imageries and products from Insat and Eumetsat down loaded through internet were utilized throughout the year. Using of Himawari8 satellite imageries and products were commenced in November.

- **Improvement of Facilities/Technical Advancement:** Observations at Meteorological office, Trincomalee (43418) was commenced .links with RIMES was continued under the project Reducing Risks of Tsunami, Storm surges, Large Waves and other natural hazards in low elevation coastal zone. Under this program, to improve the forecasting capability of department activities on training and utilizing WRF model was done Issuing of seasonal rainfall forecast under experimental basis was continued. Monsoon forum was also held two times per year with the both technical financial support of RIMES. The forums were very successful discussing with the stake holders on rainfall analysis of last monsoon and the forecast for up coming monsoon.RIMES with the collaboration of INCOIS established a " Integrated Ocean Information System for Sri Lanka and wave rider buoy will be deploued in Sri Lankan sea in 2016. Preparing of three day forecast using WRF with 5Km resolution was also continued.The project "Improving of Meteorological Observations, Forecasting and Dissemination" funded by JICA was on process and some experts were also dispatched.Two Doppler radars will be installed in the both East and West coasts of Sri Lanka under the project. Capacity building is done in Sri Lanka and it is scheduled to be done in Japan also during up coming years.

1.1.9. Thailand

Details of meteorological activities carried out by Thailand in relation to the Meteorological Component during 2015 are given below.

- Thai Meteorological Department (TMD) uses its own NWP products. The model is composed of 3 domains: Domain-1 is resolution grid 18 kilometer square, Domain-2 is resolution grid 6 kilometer square and Domain-3 is resolution grid 1 kilometer square.High resolution WRF Bangkok model (resolution1x1 km. vertical 35 levels) was run at TMD for urban weather forecasting and improvement for Bangkok and vicinity short range weather forecast.
- **Operational Room**- Operational Room at Weather Forecast Bureau of TMD is under development for meteorologist who can use observations, seismic, numerical weather prediction and climate models data, to support them. The very short range, short range, medium range and long range forecast will also be given to the relevant authorities, also to public and private agencies for management purpose.
- **Meteorological Satellite** – Japan government, through Japan trust fund with WMO has provided Himawari Cast, received station and related software for TMD. Himawari Satellite tool is established at the top TMD’s building and can measure every 10 minutes and operates on routine.
- **Weather Radar**-TMD’s radar network totally 26 sites, compose of S-band Doppler radar 5 stations, C-band Doppler radar 16 stations, X-band Doppler radar 5 stations. TMD will establishment a new C-band Doppler radar at Nan station of Nan province and also a new one to replace the old C-band Doppler radar of Ubon Ratchathani station in 2016. JMA transfer the weather radar composite technique to TMD, through operated radar composite on routine.
- **Telecommunication**-In 2016, TMD will develop the global telecommunication (GTS) to integrate data support ICAO.

1.2 HYDROLOGICAL ACTIVITIES

1.2.1. WMO activities

1.2.1.1. Associated Programme on Flood Management (APFM)

The Associated Programme on Flood Management (APFM) is a joint initiative of WMO and the Global Water Partnership (GWP). Its objective is to promoting the concept of Integrated Flood Management (IFM), minimizing loss of life due to flooding and optimizing the net benefits derived from floodplains. As such, it proposes a paradigm shift from flood protection to flood management, in line with the Sendai Framework for Disaster Risk Reduction, where the emphasis has shifted to include not only protection from hazards, but also the concept of "building back better".

Since its inception in 2001, the Associated Programme on Flood Management has had several achievements, namely:

- advancing the concept of Integrated Flood Management (IFM) through a concept paper (currently in its third edition) and a policy paper series focusing on the institutional, legal, social, economic and environmental aspects of IFM;
- developed 25 tools on specific topics related to IFM, providing guidance and know-how to flood management practitioners willing to adopt an integrated approach to flood management, comprising both structural and non-structural measures;
- disseminated the concept and core aspects of IFM in more than 130 countries, within more than 450 institutions around the world, and through its website reaching more than 330,000 views since 2007, and disseminating information of IFM and APFM activities at an average of 6 international conferences or meetings each year;
- provided capacity-building in IFM throughout the world through more than 40 workshops in 27 countries, training more than 1000 participants;
- implemented (or is currently implementing) pilot projects on IFM in 18 countries in Asia, Africa, Europe, and South and Central America, covering community-based flood management, transboundary flood management, development of national strategies for flood management, and flood forecasting and early warning systems.

WMO Congress during its Fifteenth Session "appreciated the activities under the Associated Programme on Flood Management, which had helped achieve the objective of disaster risk reduction and provided technical support to countries in flood management policy formulation. It welcomed the establishment of the Help Desk services as a tool for providing support on flood management policy issues in collaboration with other partners." Through Resolution 20 (Cg-XV), Congress decided "That WMO should continue its advocacy for a widespread adoption of an Integrated Flood Management approach at the basin, national and international levels".

Moreover, under Resolution 4 (CHy-XIII), the Commission for Hydrology decided "To assist setting up of a HelpDesk for Integrated Flood Management for the benefit of Members in the areas of flood management policy and strategy, and capacity building in support thereof."

The IFM Help Desk is hosted in WMO but depends on a strong decentralized network of experts and specialized institutes, called "Support Base Partners" (SBPs), providing input on advice and advocacy for flood management policy and strategy formulation; technical advice on the (inter-) national, regional and local level; facilitation of workshops and trainings supporting the Integrated approach of Flood Management; development and provision of flood management tools and capacity building material; and formulation of objectives and scoping for flood management proposals. Currently the network includes 26 partner institutions, comprising of NHMSs, private sector companies, Universities, other International Organizations and NGOs.

Since its inception in 2009, the IFM HelpDesk has successfully responded to more than 170 requests from over 40 countries, focusing on capacity building and technical guidance on flood management issues.

The success of APFM has inspired the development of the Integrated Drought Management Programme (IDMP), which focuses, with a similar approach, on drought-affected regions and deals with drought-related issues in an integrated way. Both APFM and IDMP are part of the GFCS User Interface Platform.

The APFM is funded through extra-budgetary contributions (currently from the Government of Switzerland, Mexico, France and USAID/OFDA; in the past from the Governments of Japan, the Netherlands, Italy and Germany).

The APFM is governed through Advisory and Management Committees (AC/MC), meeting on a yearly basis to review the progress of the last year and to formulate a work-plan for the incoming year.

At its last meeting in September 2015, noting that the APFM is already presented on GFCS website as a GFCS project, the AC/MC suggested that the HelpDesk be broadened for the climate and water communities using the GFCS platform to address climate service needs in the implementation of Integrated Water Resources Management in the context of climate variability and change. This would help strengthen existing capacities on flood management using climate services.

Moreover, the integrated approach promoted by APFM, focusing on prevention and reduction of existing disaster risk, has been also identified by AC/MC as a strong entry point to the Sendai Framework for Disaster Risk Reduction. The Sendai Framework aims to reduce substantially disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries. Its goal is to prevent new - and reduce existing - disaster risk through the implementation of integrated measures inclusive of economic, structural, legal, social, health, cultural, educational, environmental, technological, political and institutional.

APFM has been since its inception focusing on this multi-disciplinary approach, and would be able to assist in the four Priorities of the Sendai Framework (Understanding disaster risk; Strengthening disaster risk governance to manage disaster risk; Investing in disaster risk reduction for resilience; and Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction; enhancing the role of stakeholders, international cooperation and global partnerships) highlighting its focus on taking preventative measures to reduce exposure to risk prior to the onset of event and in preparedness for response and recovery, activities thereby strengthening societal resilience.

To complement this multi-disciplinary approach, the WMO Flood Forecasting Initiative Advisory Group (FFI-AG), which was created by Resolution 15 (Cg-XVI), met 1-3 December 2015 and requested that the APFM Technical Support Unit (TSU) undertake an inventory of the existing guidance material and/or training material and/or expertise through its Support Base already available through the IFM HelpDesk on flood forecasting and warnings. It also

requested the APFM TSU to design an appropriate interface to offer assistance (in line with the existing "Get Help" and "Help Yourself" options) in the field of flood forecasting and warnings and solicit feedback from selected FFI-AG members. This activity is seen as an important step allowing the WMO/GWP Associated Programme on Flood Management to offer increased assistance through its HelpDesk for Members wishing to strengthen their End-to-End Early Warning Systems (E2E EWS) for flood forecasting.
APFM has implemented various pilot project and training workshops in the region:

1.2.1.1.1. Coastal Flood Management in Bangladesh

The Bangladesh Water Partnership requested APFM for support through the Integrated Flood Management (IFM) HelpDesk. The support had the following objectives: to introduce IFM concepts and tools to the top management of relevant agencies and stakeholders; to analyse the current flood management practices in the coastal zone and develop consensus on what constitutes an integrated approach to flood management in the coastal zone; to obtain feedback from stakeholders on the current coastal flood management policy and practice; and to develop a first draft of an Integrated Flood Management framework for the coastal areas of Bangladesh.

A two-day workshop was held in April 2015 with over 100 participants, including the Minister of Water Resources, Directors from the government agencies dealing with water, national and international civil society organizations, academia and potential financial partners. The presentations and discussion in the workshop elucidated the main flood related issues in the coastal areas, namely:

- flood management decisions are frequently taken independently from land and water management, ecosystems and infrastructure;
- women are excluded from decision making processes at the local level;
- embankment heights are not adequate for rising sea level and storm surges, which is a particularly urgent need considering siltation of river beds;
- technical solutions with narrow scopes are implemented without considering maintenance of infrastructure;
- foreshore afforestation to reduce impact of storm surges has been limited;
- limited stakeholder involvement in the design and implementation of revamping infrastructure;
- limited current forecasting ability of coastal flooding (tidal flood and storm surge), only cyclone forecast and tidal height, no combined flood height forecast in the coastal zone – a consequence of limited coordination between meteorological and hydrological services;
- drainage of polders is often problematic, causing water logging, leading to breaking of embankments by communities; and
- cyclone shelters are available for people, but their assets remain unprotected.

The APFM also provides technical backstopping to the development of a national strategy, liaising also with the joint CHy/JCOMM initiative Coastal Inundation Forecasting Demonstration Project (CIFDP).

1.2.1.1.2. Flash Flood Guidance System (FFGS) Information Note

Resolution 21 (Cg XV) was adopted to enhance cooperation between national meteorological and hydrological services for improved flood forecasting and to support the implementation of demonstration projects such as the Flash Flood Guidance System (FFGS) with global coverage. A Memorandum of Understanding (MoU) was concluded in 2009 for establishing a cooperative initiative among the World Meteorological Organization, the Hydrologic Research Center, the National Weather Service of the U.S. National Oceanic and Atmospheric Administration, and the U.S Agency for the International Development Office for U.S. Foreign Disaster Assistance for the Flash Guidance System (FFG) with global coverage project. The goal of the initiative is to disseminate and implement technologies that provide early warnings for flash floods, especially in developing countries where no such flash flood early warning capability exists.

Within the framework of the MoU, the Southern Africa Region Flash Flood Guidance (SARFFG), Mekong River Commission FFG, (MRCFFG) and Black Sea and Middle East (BSMEFFG) have been implemented, while, a series of projects are under implementation, including South East Europe FFG (SEEFFG), Central Asia Region FFG (CARFFG), South Asia FFG (SAsiaFFG) and Southeastern Asia-Oceania FFG (SAOFFG).

The MRCFFG includes Cambodia, Lao PDR, Thailand and Cambodia. The MRC is the Regional Centre for the project. Training for the MRCFFG last took place in June 2015 in Phnom Penh, Cambodia, and included the participation of Myanmar forecasters. Efforts have been underway to seek MRC concurrence to have Myanmar participate in the MRCFFG project.

The SAsiaFFG includes Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka. The planning workshop for the project was held in Kathmandu, Nepal, from 26 to 28 November 2012. The first Project Steering Committee meeting is to be held in New Delhi, India, from 26 to 28 April 2016. The planning workshop had proposed two regional centres for the project, one in Pakistan and one in India. It is anticipated that the upcoming meeting will attain agreement on a path forward for implementation of the project.

The major activities that have been conducted over the last year include: the CARFFG initial planning meeting, which was held in May 2015 in Ankara, Turkey, and its first Steering Committee Meeting, which was held in September 2015 in Astana, Kazakhstan. CARFFG of operational training of forecasters took place in February 2016 in San Diego, USA with the participation of two experts from each Central Asia NMHS except Turkmenistan. Two forecasters from the BSMEFFG (Lebanon) also participated in the operational training.

Development of the FFGS modelling effort for the SEEFFG project was completed and will soon be installed on the servers in Turkey, the Regional Centre for the project. Operational training was provided to the forecasters of the participating countries in San Diego, USA June 2015. The final step in going fully operational is the successful participation of forecasters in the training session to be held in Zagreb, Croatia, in May 2016.

The SAOFFG initial planning meeting was held in Jakarta, Indonesia, in February 2016 in which participants agreed on the development and implementation of SAOFFG project. Participants also thought that the regional NMHSs would benefit from the parallel, rapid implementation of Severe Weather Forecasting Demonstration Project (SWFDP) coincident with the SAOFFG project in the region.

A technical meeting for advancing the development of the Concept of Operation (CONOPS) on the integration of SWFDP-Southern Africa and Southern Africa Region FFG (SARFFG) project was held in Pretoria, South Africa, in October 2015. Disaster Management Agencies and representatives form the NMHSs of participating countries concluded that close cooperation between the agencies will be most beneficial for saving lives and reducing property damages.

FFGS Programme Meeting, which includes all MoU partners, was held in Geneva in July 2015. Participants agreed on the need to enhance FFGS capabilities by including: landslide susceptibility mapping; urban area flash flood early warnings; scalable and expandable riverine routing (river scale flood forecasting); and multiple mesoscale numerical weather model ingestion.

There is a proposal to hold a "Global Flash Flood Guidance Workshop: Advancing Operational Use". The event is to be held in Turkey in March 2017 and is to be funded through contributions from USAID/OFDA. The intent is to being together practitioners to share experiences, identify strengths and weaknesses of the system, and discuss sustainability issues.

1.2.2. Bangladesh

The representative of Bangladesh informed the panel that Modernization of hydrological networks include (1) upgrading 308 manual water level stations to be equipped with automatic data collection and reporting in real-time; upgrade 257 rain gauges to automatic and real time; upgrade 10 existing climate stations operated by BWDB; and upgrade or establish 1100 groundwater stations and nests of various configurations to automatically report measurements; (2) purchase of 4 catamarans and 4 survey boats for coastal hydrographic survey and stream gauging; (3) purchase 10 vertical profiling ADCPs; (4) purchase of 20 water quality sondes for measuring salinity and total dissolved solids (TDS); (6) purchase 8 echosounders to support river gauging and river morphology measurements.

1.2.3 India

1.2.1.1. Flood monitoring and forecasting mechanism

Flood is one of the natural calamity which causes huge loses of life and property in each year. In India Flood Forecast is the joint responsibility of India Meteorological Department (IMD) and Central Water commission (CWC). IMD is the nodal agency for issuing Quantitative precipitation Forecast (QPF) for river basins/ sub-basins where as CWC is the nodal agency for issuing Flood Forecast. The QPF is used as the input in the Flood Forecasting model of CWC .

There are 10 Flood Meteorological Offices(FMOs) at different parts of flood prone areas of the country which are located at Agra, Ahmedabad, Asansol, Bhubaneswar, Guwahati, Hyderabad, Jalpaiguri, Lucknow, New Delhi and Patna in the flood prone areas namely the river catchments Yamuna, Narmada, Tapi, Ajoy, Mayuraksi and Kangasbati, Mahanandi, Brahmani and Subernarekha, Brahmaputra, Dhansiri and Barak, Godavari and Krishna, Teesta, Ganga and Sharada, and Sahibi, Kosi, Baghmati, Gandak etc. IMD also provides similar support to Damodar Valley Corporation (DVC) for the river basins Barakar and Damodar.

Flood Meteorological Service is provided daily, consisting of following inputs to Central Water Commission (CWC) issuing Hydromet Bulletins which contains the following information:

i. Sub-basin wise QPF,
ii. Synoptic situations,
iii. Spatial and temporal distribution of rainfall,
iv. Heavy rainfall warnings,

v. Sub-basin wise past 24 hr realized rainfall.

QPF bulletin is issued at 0930 hrs IST and Hydromet Bulletin at 1230 hrs IST by FMOs. Forecast for a lead time of 5-days (forecast for 3 days and outlook for subsequent 4 days) are issued daily during flood season which may be modified in the evening when situation warrants. In the flood season, year 2015, 22679 no of QPF have been issued out of which 13660 are correct over the river catchment and in annual consolidated forecast report "Correct Forecast" has been found about 60%. QPF Bulletins including heavy rainfall warning are also issued by concerned FMOs during cyclonic period or when there is a chance of heavy rainfall leading to flood.

The are operational run of sub-basin-wise WRF (00UTC & 12UTC) and MME (00UTC) models' output (1-day, 2-day and 3-day) for rainfall are generated and uploaded on IMD website for 122 sub-basins under FMO which is an additional guidance to forecaster for issuing QPF. In the flood season 2015, IMD GFS model rainfall products became operational for basin/sub basin level for 7 days which was very useful for water management.

1.2.3.2.Major New Initiatives

1.2.3.2.1 Modeling of changing Water Cycle and Climate

A project entitled "Modeling of changing Water Cycle and Climate" approved for implementation jointly with NCMRWF during XII FYP. The main objectives of the program are as follows:

i. To augment the present hydro-meteorological observing systems especially in the Himalayan glacier region. Two river basins **Narmada** and **Satluj** has been chosen for this pilot study.
ii. To develop basin scale high-resolution modelling system to enhance predictions of hydro-meteorological variables
iii. To develop integrated basin-scale hydrological modelling system by incorporation of conventional and satellite data and to generate a quantified estimate of water balance in the river catchment basins of Narmada and Satluj
iv. Creation of hydro-meteorological information system at basin scale
v. To investigate the impact of climate variability and change scenarios on hydrological response at basin level

1.2.3.2.2. GIS based customized rainfall information system (CRIS)

GIS based customized rainfall information system (CRIS) made operational for processing real time rainfall data to generate state, sub-division, district and river basin wise products for operational use.

1.2.3.2.3. NWP model based QPF

NWP model based QPF has been commenced so that the gridded output of the model is being utilised for running the hydrological model by CWC. It has started on a pilot basis and will be extended for all the river basins.

1.2.4. Oman

The representative of Oman informed that during the year 2015, a measurements of all hydrological parameters were measured through (4692 monitoring stations). Stations includes (rain gauges, wadi gauges, flow peaks, channels , springs and water level) in addition to 49 dams distributed all over the Sultanate.

1.2.4.1. Rainfall:

During the year 2015, the highest amount of rainfall in:

- Dhofar governorate (south of Oman) reached (393 mm) in Salalah.
- In Cyclone Chapala recoreded (85 mm) in Hasik on Arabian sea coast.
- In South Batinah (208 mm) in Nakhal
- In the North East (205 mm) in Ibra
- In the South East (202 mm) in Maseirah after storm Ashabaa hit easten coast.

1.2.4.2. Wadi flow and floods:

The year 2015 is considered one of the years where low discharge rates were recorded. The total flood volumes during 2015 was estimated (133 Mm3) which is below the annual average (330 Mm3) . The highest amount of flooding the governorate of South East (45 million m3) in storm Ashabaa

1.2.4.3. Groundwater level measurements:

Analysis of data showed that as a result of decrease in recharge there is a gradual decrease in water levels in most areas of the Sultanate, except Muscat and South Sharqiyah governorates.

1.2.4.4.Dams:

A total of 144 Mm3 was retained by recharge dams during 2015 was the highest during the floods in September (81 million m3).

During the year 2015 the Ministry arranged for both local and overseas training and workshops

The training Program	No. of Trainers
Monitoring , processing and analysis of water Resource Data	15
GIS & Arcmap	15
Direct & indirect survey measurements Method for Floods	18
Geology of Oman	15

1.2.5. Pakistan

1.2.5.1. Flood forecasting method

Flood Forecasting Division (FFD) is a dedicated unit of Pakistan Meteorological Department for the issuance of Hydro meteorological flood information's in all the major rivers and nalullahs of Pakistan. These information's are based on the different types of data obtained from the network of 46 river gauge stations maintained by wapda and irrigation departments, a telemetric rain gauge network of 45 stations and a network of 35 telemetric discharge stations installed in the the catchments of river Indus , Jhelum, Chenab, ravi, Sutlej and on major nullahs. Another set of data is received from the meteorological observatories owned by PMD. The information from five C-band radars at Sialkot, Dera Ismail Khan, Islamabad, Rahim Yar Khan and Karachi and two S-band QPM Doppler weather radars at Mangla and Lahore is incorporated to this for having real time weather situation over the ungauged area. All this information is blended with the Synoptic situation on the weather charts and a future scenario is developed. The hydrological forecasting models FEWS, IFAS, CLS, and statistical are also consulted along with global Meteorological Forecasting Models. On the basis of these information's, two Bulletins are daily issued during the flood season from 15 June to 15 Oct each year. The 'Bulletin A' contains the qualitative information regarding the Synoptic Situation, prevailing Flood Situation, rainfall amount observed during last 24 hours and the Flood Forecast for the next 24 hours in the country. It also contains a further outlook for next 24 to 72 hours based on the future weather conditions. The 'Bulletin B' is the quantitative hydrological version of the 'Bulletin A' containing the values of prevailing river Flows and the Forecasted values for the next 24 hours at all structures of all the rivers starting from the Rim stations down to Kotri in the Indus River Basin. This Bulletin also contains the Dams level, expected Flood level in the rivers and the weather forecast particularly in the upper catchments of all the Major Rivers. If any significant Flood situation is expected, then significant flood information is also issued. Advisories are issued regularly to the Flood mitigation agencies for taking precautionary measures for the safeguard of the general public. The most recent addition to the Flood information has also been started in the form of inundation maps created by the combination of different Flood routing Models. The flood information is disseminated by FFD to more than 300 addresses including the federal government and provincial government functionaries, mitigation agencies, print & electronic media as well as Pak Army.

1.2.5.2. Hindu Khush Himalayan Region (HKH-HYCOS) Project

In wake of Super Floods 2010 in Pakistan, the International Centre for Integrated Mountain Development (ICIMOD) based in Nepal", implemented the project "Establishment of Regional Flood Information System in the Hindu Khush Himalayan Region (HKH-HYCOS)" in order to promote regional cooperation in flood risk reduction and to cope with future flood disaster in Pakistan with Federal Flood Commission (FFC) being the coordinating agency while WAPDA and PMD are main beneficiaries of the project. Under this project, three (03) AWS have been installed in flood affected areas in Gupis, Kalam and Lower Dir. The data from these AWS has regularly been shared among ICIMOD Member countries via a website http://hkhhycos.pmd.gov.pk. Further in the aftermath of Floods 2010 in Pakistan, UNESCO in collaboration with JICA/Government of Japan initiated a project "Strategic Strengthening of Flood Warning and Management Capacity of Pakistan" phase-I in July 2011 in order to improve the flood forecasting and early warning capabilities of Pakistan to effectively cope with such hydrometeorological disaster risk reduction challenges in the country in future. The main beneficiaries of the project at national level were including Pakistan Meteorological Department, Federal Flood Commission (FFC), Pakistan Space and Upper Atmosphere Research Commission (SUPARCO), and National Disaster Management Authority (NDMA).Under the first phase of the project, International Centre for Water Hazard and Risk Management (ICHARM) under the auspices of UNESCO and Japan Aerospace Exploration Agency (JAXA) developed a flood forecasting and routing model Indus-IFAS (Integrated Flood Analysis System for River Indus) and was put into operation at PMD's Flood Forecasting Division (FFD), Lahore for dissemination of lead-time flood warnings to the communities living in flood plains of the upper Indus and Kabul River. The project was completed in June 2014. However, after September 2014 floods in the Eastern Rivers and in order to improve Indus-IFAS, there was considered a dire need to extend the Indus IFAS system to cover the whole Indus River catchment including the Eastern Rivers of Jhelum, Chenab, Ravi, and Sutlej. Therefore, upon request of Pakistan, UNESCO and Govt. of Japan showed their concurrence to implement IFAS Phase II of the project in order to increase the accuracy and reliability of Flood Early Warning System in Pakistan for mitigating hydrometeorological disasters for the safety and prosperity of people of Pakistan. The phase II of the project was launched in March, 2015.

1.2.5.3. Standardisation of flood forecasting and warning approaches

An International Workshop on "Standardizing Flood Forecasting and Warning Approaches in Transboundary Catchments" was jointly organized by PMD and UNESCO at Lahore, Pakistan on 19-20 April, 2016. This workshop is part of phase-II of UNESCO's "Strategic Strengthening of Flood Early Warning and Management Capacity of Pakistan" Project. The workshop was attended by representatives from national and international partner organizations such as ICHARM, Japan Aerospace Exploration Agency (JAXA), PMD, NDMA, Provincial Disaster Management Authorities (PDMAs), FFC, universities, provincial irrigation departments and international experts from Australia, France, Indonesia, Korea and Japan. The participants shared their knowledge to further enhance the river modelling and flood forecasting models for Indus and the Eastern Rivers.

1.2.5.4. Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan

Owing to high vulnerability of glaciated northern part of the Pakistan to Glacial Lake Outburst Floods (GLOFs), PMD under the auspices of UNDP recently carried out a project "Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan". Under this project, science and community based GLOF Early Warning System has been established at three (03) pilot sites in northern area (Bagrot valley in Gilgit, Bindogol and Golain valleys in Chitral). In wake of establishment of GLOF EWS in the pilot valleys local communities were got involved. Community sensitization campaigns were launched which include the consultative meetings with community elders, discussions with locals, awareness about the water and environmental hazards and also apprised them the importance of the GLOF Early Warning. Pamphlets were also distributed to the communities regarding the awareness of GLOF events besides lectures and training sessions. This community based EWS played important role in saving the live and property of local people during previous year monsoon/flood season. He added that PMD with the financial assistance of UNDP and in cooperation with National Agricultural Research Council (NARC) has introduced a new updated Glacial Lake Inventory. As per this inventory there are 3044 glacial lakes in Hindu-Kush-Karakorum-Himalaya region of Pakistan. Among these lakes 36 are classified as potentially dangerous.

1.2.6. Sri Lanka

1.2.6.1 Flood forecasting method

Irrigation Department (ID) is the mandated Institution working with hydrological issues in Sri Lanka. As the pioneer organization responsible for developing water resources, ID formed the Hydrology Division (HD), by 1947, in order to collect hydrological data and information required for Planning Reservoirs and Flood Control Works. The Hydrology Division gradually expanded the hydrological data collection network covering around 30 major rivers of the country. At present it is providing the hydrological data and information to all government and nongovernmental organizations responsible for water related infrastructure development and disaster management.

The prediction for Second Inter Monsoon for 2015 and North East Monsoon (December-January) by the South Asian climate outlook forum was for normal to above normal rainfall. The consensus forecast outlook for monsoonal rain and temperature over South

Asia have being developed through an expert assessment of the prevailing global climate conditions. Irrigation Department of Sri Lanka received this message in October 2015 at the South Asian Climate Outlook Forum. These forecasts were reviewed during the Monsoon Forum After careful assessment of current water levels in the reservoirs, Irrigation Department issued special instructions to the Irrigation engineers in-charge of reservoir operations, to maintain reservoir water levels 1m below the full capacity level, allowing flood detention and also for smooth operation of radial gates in the spillways.Monthly seasons outlook prepared by the Department of Meteorology was also received through emails and they were used for water management.

It was a relief to the Irrigation Department and to the government, the ability of minimizing the flood damage and also keeping the farming community alert over the possible inundation due to excess drainage based on the weather forecast.

1.2.7. Thailand

For hydrology and water management in the country come mainly under the care of two government agencies - Royal Irrigation Department (RID) and Department of Water Resource (DWR). There are 25 main river basins in Thailand

- The area affected by Tropical cyclones are the western region of Thailand. During 1St of April 2015 until end of March 2016, the trend of the precipitation is a bit less than average compare with the past record. It’s the main reason to make the capital water in the reservoir is rather less than normal and this cause the strong drought area all of Thailand. So farmer stop to do rice crop in summer season. RID water management by water supply and protect ecology only.
- The RID has strategies for flood prevention and mitigation, as well as impacts in urban and cultivated areas, with aims to reduce the loss of lives and properties of population at risk. Management plans are set in terms of monitoring, predicting and warning by establishment of Water Watch and Monitoring System for Warning Center (WMSC) to examine flood situations 24 hours. In addition, the collaborations with national related agencies for implementation plan cope with local flood protections in economic zones where severe flood may occur.
- The state-of-art technologies were established, such as telemetry and flood forecasting systems. Similar to 544 manual river gauges (27 stations decrease from 2013) and 2,294 manual rain gauges, 23 of 25 main river basins have 710 telemetric stations and 430 telemetric micro stations installed for water resources management and flood prevention and mitigation.
- RID collaborates and discusses with other agencies to take decisions during flood situation under the government to reduce the loss from Typhoon and tropical cyclone-related disasters for monitoring and analysis of flood situation.
- Coordinate and exchange information of climate, rainfall, run off and water operation to analyze and forecast the future situation for water management before announcement to public.
- To improve the telemetering system to the rural area which is the high risk area for flood warning and develop the communication system to disseminate flood information like on website or text messages.

1.3 DISASTER PREVENTION AND PREPAREDNESS

1.3.1. WMO activities

1.3.1.1. Disaster Risk Reduction

1. The seventeenth World Meteorological Congress in June 2015 (Cg-17) reaffirmed DRR as one of the high-priority areas for WMO, thereby acknowledging the significance of the Sendai Framework for WMO and the new opportunities and challenges it poses for National Meteorological and Hydrological Services (NMHSs). The scope and objectives of the WMO DRR Programme, established in 2003, were aligned with the HFA to support NMHSs in: the provision of hazard information for risk assessments, prevention, response, recovery and risk transfer across sectors; the preparedness through early warning systems (EWS); the ability to respond to user requirements and the cooperation and engagement in disaster governance structures at all levels. Through this crosscutting Programme, WMO has played an important role in supporting its Members in implementing the HFA. The WMO DRR priority cuts across all the other priorities of the Organization and contributes to related priorities such as capacity development and the implementation of the GFCS.
2. WMO is now realigning its DRR Programme with the Sendai Framework, while considering the provisions of other global frameworks that are highly relevant to DRR, for example, on sustainable development, climate change, humanitarian assistance and urban issues. A first step was the decision by Cg-17 and the Executive Council (EC) to produce and regularly update a WMO DRR Roadmap (see Annex I). This document will guide WMO activities in all components of disaster risk management as well as their further enhancement and coordination across WMO constituent bodies and programmes. The Roadmap is a coordinated organization-wide plan of action with prioritized activities and deliverables. It will be continuously updated and verified for consistency with the WMO Strategic and Operating Plan by its constituent bodies as well as the work plans for related WMO programmes and projects. Furthermore, the Roadmap considers relevant WMO guidelines and documents as well as input from NMHSs' own DRR roadmaps, frameworks and good practices.
3. A network of DRR Focal Points of the technical commissions (TCs) and technical programmes (TPs) (DRR FP TC-TP) had been created through nominations by the Presidents of TCs (PTC) and relevant coordinating mechanisms of TPs and inter-commission activities. Cg-17 reconfirmed the establishment of the DRR FP TC-TP and requested to include focal points of the regional associations (RAs) as a mechanism to support the WMO-wide coordination of DRR activities. The presidents of the RAs and TCs then nominated (or reconfirmed) respective DRR Focal Points (now DRR FP RA-TC-TP). Their first meeting was held from 3-5 November 2015 (see summary in Annex II). Cg-17 furthermore encouraged the Secretariat to continue with user-driven approaches such as the User-Interface Expert Advisory Groups (UI-EAGs) in the development of DRR knowledge products, science-based and risk-informed services, and in the implementation of demonstration projects as detailed in the DRR Roadmap and its Work Plans for the DRR Programme.
4. Following Cg-17, EC-67 in June 2015 established the new ECWorking Group on DRR (EC WG-DRR) to provide guidance on the implementation of the WMO DRR priority in

the WMO Strategic Plan 2016-2019. By doing so and by committing to the implementation of the UN Plan of Action on DRR for Resilience (http://www.preventionweb.net/files/33703_actionplanweb14.06cs1.pdf), WMO will also assist Members to implement the Sendai Framework.

1.3.1.2. WMO DRR Roadmap

1. A zero draft of the WMO DRR Roadmap was developed by the WMO Secretariat, assisted by a number of Members (Canada, China, Japan, United Kingdom, and the United States of America), for consideration by Cg-17 in May 2015, at the request of the EC-66 in June 2014. Specifically, EC-66 requested the WMO Secretariat, "in consultation with Members, to urgently develop a WMO DRR roadmap of prioritized and realistically achievable activities and deliverables that are consistent with the WMO Strategic and Operating Plans as well as the work plans for relevant WMO programmes and projects". In addition, EC calls for a clear identification of the role of NMHSs and WMO, working with their partners, in the implementation of international planning processes, such as the Sendai Framework for DRR 2015-2030, the successor to the HFA.
2. The EC request was timely since 2015 marked a pivotal year in the global development agenda: The Sendai Framework was adopted at the WCDRR in Sendai in March 2015, the Third International Conference on Financing for Development (Addis Ababa, Ethiopia, July 2015) resulted in an intergovernmentally negotiated and agreed outcome on financing sustainable development and in September 2015, the United Nations Summit adopted the 2030 Agenda for Sustainable Development with a set of Sustainable Development Goals (SDGs), of which disaster risk management for achieving DRR is an integral part. In addition, the Paris Agreement, a new international and binding climate change agreement, was adopted at the 21st Session of the Conference of the Parties (COP21/CMP11) to the United Nations Framework Convention on Climate Change (UNFCCC), in December in Paris, to be implemented from 2020 onwards. Negotiations on this treaty include measures to reduce and transfer disaster risk and how to deal with loss and damage if climate change mitigation and adaptation are not sufficient. This rare alignment of international policy processes with national government, private sector, and civil society interests is an opportunity to position disaster risk management as a cornerstone in efforts to foster DRR, climate change adaptation (CCA) and resilience, together with sustainable development.
3. In addition to this global development agenda, an increasing number of actors are demanding access to timely multi-hazard / climate change warnings and information in order to better inform their own tactical strategic decision making. For many of these actors the demand for information is being successfully realised through WMO Members, however this demand is also being served by 3rd party organisations including regional intergovernmental bodies, the private sector and non-governmental organizations (NGO's). On the grounds that this could potentially undermine the role of the local NMHS and lead to a confused message for decision makers, it is therefore important that the Roadmap also acts as a vehicle by which WMO looks to improve coordination / collaboration with respect to the global response to the current DRR-focused development agenda.

4. The Roadmap is first and foremost a document that can be used by both WMO Members and the external side to understand how NMHSs can contribute to increasing the resilience of communities, nations, regions, and the world under the above-mentioned frameworks, through a coordinated WMO-wide plan of action for DRR. It is neither a reference document for the theoretical or practical aspects of DRR nor a separate project or programme. However, it will discuss the activities required to address DRR as one of seven WMO priority areas in its Strategic Plan 2016-2019. Therefore, a key feature is to utilize existing WMO mechanisms (constituent bodies and programmes) and their plans and expert groups wherever possible, above all the WMO DRR Programme, identify synergies to leverage WMO activities and projects to realise a DRR vision for NMHSs and the Organization and, if appropriate, forge links to external initiatives. In this way, the document is a means for the cross-cutting DRR Programme to achieve its goals. This comprehensive, cross-cutting set of activities will also contribute to the realization of other WMO priorities such as the Global Framework for Climate Services (GFCS) and capacity development.
5. The Roadmap will cover four inter-sessional periods of WMO, corresponding to the 15 year lifetime of the Sendai Framework, and will align closely with a number of existing global conventions and international development frameworks under development (e.g. on humanitarian and urban issues), as well as WMO frameworks and strategic documents. Each financial period may have different phases in terms of development, implementation, operation and evaluation. The period 2016-2019 may consist mainly of the establishment of a baseline, DRR components of existing projects and activities, and new pilot activities. The timescales involved require the Roadmap to be a "living" document which will define an initial set of activities and identify key milestones along this journey towards a "DRR service-ready" NMHS and Organization over all. Over the course of time the DRR landscape is certain to change and this initial document will necessitate regular updates and therefore further endorsement from the WMO decision-making bodies.
6. Specific objectives of the Roadmap are – assisted and coordinated by the WMO DRR Programme – to:
   - Provide a framework for WMO Members to enhance NMHSs' contributions to national DRR efforts;
   - Provide a mechanism to enhance WMO programmatic coordination and collaboration in respect of DRR;
   - Reference developments in capability such as impact-based forecasting and risk-informed warnings of multiple hazards; and,
   - Identify both tactical and strategic opportunities to enhance the role of hydrometeorology and therefore of NMHSs and WMO in global and regional DRR fora (including coordinated and focused engagement with the international DRR stakeholder community, e.g. the United Nations system, regional and sub-regional organizations, the private sector, charities, NGOs, etc.) and in the implementation of relevant international frameworks and processes.
7. The structure of the current draft of the Roadmap document can be outlined as follows:

- Executive summary

- Preamble (EC/Cg requests, initial consultations, nature of the document, other background information)
- Introduction (rationale, concepts, vision, objectives, structure of the document)
- Benefits of the Roadmap to Members (social, economic, environmental, coordination)
- Identification and design of priority activities (per thematic area aligned with the Sendai Framework and per activity pillar, internal and external linkages and interactions, future consultations, regular updates, etc.)
- Priority activities (2016-2019) (baseline establishment and prioritization, supporting the 4 priorities for action of the Sendai Framework through identifiers for cataloguing extreme hydrometeorological events, strengthening the NMHSs' role in their national disaster risk governance, risk prevention and mitigation in sectors, and strengthening MHEWS and (humanitarian) disaster response)
- Implementation framework and approach (governance, implementation and user-interface mechanisms and their roles and responsibilities; timeline / timeframes, financial and resources considerations, communication and outreach, monitoring and evaluation, etc.)
- Concluding remarks
- A draft Work Plan 2016-2017 (as a separate document)
- Annexes (Cg/EC references, key elements of the Sendai Framework, internal and external linkages, acronyms, etc.)

8. The new draft WMO DRR Roadmap ("Zero-Draft Version 1.2") is available on the website of the DRR Programme (http://www.wmo.int/pages/prog/drr/).
9. The First Session of the Executive Council Working Group on Disaster Risk Reduction (EC WG DRR) 4-7 April 2016 instructed the WMO Secretariat to seek further feedback from WMO Members and then present a draft of the Roadmap to EC-68 for approval. It was also recommended to EC-68 that the Secretariat develop an implementation plan for the Roadmap.

1.3.1.3. Participation of WMO in the International Network for Multi-Hazard Early Warning Systems (IN-MHEWS)

1. As identified in the Sendai Framework, EWS have been an important factor in reducing the risk of death and injury from disasters triggered by natural hazards related to weather, climate, and water. Strengthened monitoring and assessment of natural hazards and improved forecasting and warning services have contributed to this progress. Just as important, people increasingly understand the risks posed by natural hazards and the measures they should take to protect themselves and their families.
2. Advances in socio-economic development, renewed investment in DRR, and national and international actions to implement the priorities of the HFA over the past decade are among other factors that made this progress possible. These gains need to be sustained in the post-2015 era.
3. While good progress has been achieved in strengthening EWS over the 10 years of implementing the HFA, it is also true that the resulting societal benefits have been spread unevenly across countries and communities. Significant gaps remain, especially in providing services to grassroots communities and poor and vulnerable families.

4. Furthermore, the cascading impacts of natural hazards and climate change and the growing complexity of human society increasingly magnify the risks and vulnerabilities that people face. The Sendai Framework calls for enhancing and strengthening MHEWS, to develop and invest in regional multi-hazard early warning mechanisms, and to achieve the global target for MHEWS. MHEWS inform the people of the potential impacts of impending natural hazards, the risks on their lives and livelihoods, and the action they should take. To be effective, this approach entails multi-stakeholder cooperation and coordination between and among national science, disaster-risk management agencies, and other relevant stakeholders. It also needs to be combined with actions to make communities more disaster resilient so that they can respond more effectively to natural hazards.
5. In response to the call of Sendai Framework, the International Network for Multi-Hazard Early Warning Systems (IN-MHEWS) has been established as a multi-stakeholder partnership that will facilitate the sharing of expertise and best practice on strengthening MHEWS as a national strategy for DRR, climate change adaptation (CCA), and building resilience. In doing so, it will support the implementation of Sendai Framework, including the global DRR target for MHEWS, and the UN Plan of Action on DRR for Resilience.
6. As a broad-based networking initiative on early warning, IN-MHEWS will exemplify the importance of multi-stakeholder cooperation and synergy in advancing MHEWS and promoting DRR for societal resilience.

1.3.1.4. Organization of the International Conference on Multi-Hazard Early Warning Systems (IC-MHEWS)

1. The increasing emphasis on a more holistic multi-hazard approach to early warning advocated by the Sendai Framework defines a new era for early warning services built on good practices and lessons learnt by countries, organizations, and communities and the gains of earlier international efforts to advance EWS. For example, the International Early Warning Programme (IEWP) was first proposed at the Second International Conference on Early Warning (EWC II) held in 2003 in Bonn, Germany. As an implementation mechanism, the Platform for the Promotion of Early Warning (PPEW) was launched in 2004 and remained operational until 2008.
2. Currently, efforts are needed to determine how MHEWS should use and communicate risk and impact information from multiple sources and integrate technical, social and financial capacities through coordination mechanisms among multi-disciplinary stakeholders, including effective feedback mechanisms for continuous improvement. In this way, a multi-hazard approach to EWS can provide economies of scale and, eventually, sustainability of the system as a whole.
3. Cg-17 noted that for more effective and wider implementation of MHEWS, it is important to document the good practices and other national experiences in implementing MHEWS and prepare guidelines on institutional coordination and cooperation and the role of NMHSs in implementing MHEWS. There is also an urgent need for addressing trans-boundary and regional issues in developing and disseminating early warnings. To address these issues, WMO Congress encouraged the organization of the International Conference on MHEWS (IC-MHEWS) in 2016, in collaboration with appropriate international, regional and national agencies and

institutions. Accordingly, WMO and the United Nations Office for Disaster Risk Reduction (UNISDR), in collaboration with a number of other United Nations agencies, international and regional organizations as well as national agencies from a number of Member States, plan to organize IC-MHEWS in or around December 2016.

4. The IC-MHEWS will build on the outcomes of the three International Conferences on Early Warning that were held between 1997 and 2006. It will also address the priorities highlighted in the UN Plan of Action on DRR for Resilience which was endorsed by the United Nations Chief Executives Board (CEB) in 2013. IC-MHEWS will appropriately address the call for enhancing and strengthening MHEWS in the Sendai Framework adopted by WCDRR in Sendai, Japan. One of the major outcomes of the Working Session on Early Warning during the Multi-Stakeholder Segment of WCDRR was the endorsement of the proposal for the establishment of an International Network for MHEWS (IN-MHEWS). This multi-stakeholder partnership will facilitate the sharing of expertise and best practice on strengthening MHEWS as a national strategy for DRR, climate change adaptation, and building resilience. In doing so, it will support the implementation of Sendai Framework, including the global target for MHEWS, and the UN Plan of Action on DRR for Resilience.
5. The Climate Risk and Early Warning Systems (CREWS) initiative has been launched on 1 December 2015 at the twenty-first session of the Conference of the Parties (COP) and the eleventh session of the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol (CMP) – the 2015 Paris Climate Conference (COP21-CMP11) in Paris, France. Implementation of this initiative is supported by WMO, the UNISDR and the World Bank's Global Facility for Disaster Reduction and Recovery (GFDRR) which are actively involved in reducing the vulnerability and exposure of nations and communities to natural hazards. The governments of Australia, Canada, France, Germany, Luxembourg and The Netherlands have agreed to give more than US$ 80 million to equip up to 80 countries with better climate risk early warning systems. IC-MHEWS will provide a good platform for the participants from these countries to appraise themselves about the latest advances in the MHEWS and the strategies to implement them in their countries.
6. Issues related to DRR and particularly to MHEWS are closely linked to the Sustainable Development Goals (SDGs) and the Paris Agreement under the UNFCCC. IC-MHEWS will address these issues and provide the international community with a unique opportunity to present their approaches in the implementation strategies for DRR. For example, the achievements made in MHEWS and associated emergency preparedness and response activities by UNESCO, IOC, IHO, UNESCAP, IFRC, FAO, WHO, UNOCHA, UNDP and UNEP are quite relevant. IC-MHEWS will also benefit from early warning-related components of other international conferences, such as the UNISDR Science and Technology Conference on the implementation of the Sendai Framework for DRR 2015-2030 (27-29 January 2016).

1.3.1.4.1. Specific objectives of IC-MHEWS

The main goal of the IC-MHEWS is to take stock of current EWS and related actors, mechanisms, partnerships, projects, publications, etc. to identify effective strategies and actions needed to promote and strengthen MHEWS in support of the implementation of the Sendai Framework through the following specific objectives:

- To review the current status of observation networks, the level of data availability and access at different spatial and temporal scales;
- To assess the efficacy of available tools for monitoring, modelling and prediction, including data processing and seasonal forecasts of disaster-related factors and the ways and means to strengthen regional and international cooperation to develop science-based methodologies and tools;
- To review the good practices and lessons learnt over the past decade at the national, regional, and international levels in the provision of early warnings and supporting products and services which are delivered to disaster management agencies prior to the occurrence of different hazard events and the level of response achieved in coping with the impacts of the hazards;
- To discuss and recommend the ways to forge partnerships between the different stakeholders at the national, regional and international levels through voluntary commitments to foster and enhance cooperation, collaboration, and networking on improving EWS with a multi-hazard approach;
- To discuss the means to strengthen the interactions with the different user communities as a contribution to the DRR priority of the Global Framework for Climate Services (GFCS);

1.3.2. UN-ESCAP

ESCAP provided technical assistance and policy guidance to the Panel members. In the 71st session of ESCAP Commission in 2015, ESCAP liaised with member States and was requested to work on deepening and extending regional cooperation mechanisms.
In following up this request, ESCAP implemented the Drought Monitoring and Early Warning project benefiting 8 countries including PTC member States, Bangladesh, Myanmar and Sir Lanka. China and India has provided data, information and technical assistance for the project. ESCAP has also implemented a United Nations Development Account project on mainstreaming disaster risk reduction into national development strategies and plans, and the target countries include PTC members, Maldives and Sri Lanka.

1.3.3 Bangladesh

BMD is preparing to produce standardized alerts and warnings. Bangladesh Meteorological Department (BMD) is also planning installation of a Common Alerting Protocol (CAP) which is an international standard that is used to send public alerts and warnings. It is a digital format for changing emergency alerts that allows a consistent alert message to be disseminated simultaneously over many different communication systems. As more systems are built or upgraded to CAP, a single alert can trigger a wide variety of public warning system, increasing the likelihood that intended recipients receive the alert by one or more communities. A contract language will be developed that will result in the set up for CAP for BMD, while coordinating these activities with first responders, such as local community leaders and DDM.

1.3.4 <u>India</u>

1.3.4.1 Cyclone Warning Services

The extensive coastal belts of India are exposed to cyclonic storms, which originate in the Bay of Bengal and the Arabian Sea every year. These cyclones, which are accompanied with very heavy to extremely heavy rain, gales and storm surges cause heavy loss of human lives and cattle. They also cause extensive damage to standing crops and properties.

It is the endeavour of India Meteorological Department (IMD) to minimise the loss of human lives and damage to properties due to tropical cyclones by providing early warnings against the tropical cyclones. Cyclone warning is one of the most important function of the IMD and it was the first service undertaken by the department in1865. The cyclone warnings are provided by the IMD from the Area Cyclone Warning Centres (ACWCs) at Kolkata, Chennai & Mumbai and Cyclone Warning Centres (CWCs) at Vishakhapatnam, Bhubaneswar and Ahmedabad.

The complete Cyclone Warning Programme in the country is supervised by the Cyclone Warning Division (CWD) at Head Quarter Office of the Director General of Meteorology at New Delhi. The CWD monitors the cyclonic disturbance both in the Bay of Bengal and Arabian Sea and advises the Government of India at the Apex level. Information on cyclone warnings is furnished on a real time basis to the Control Room in the Ministry of Home Affairs, Government of India, besides other Ministries & Departments of the Central Government. This Division provides cyclone warning bulletins to Doordarshan and All India Radio (AIR) station at New Delhi for inclusion in the National broadcast/telecast. Bulletins are also provided to other electronic and print media and concerned state govts. The Head, Regional Specialised Meteorological Centre-Tropical cyclones, New Delhi monitors technical aspects and review the standard practices in the area of cyclone forecasting.

1.3.4.2 Cyclone warning bulletins

The following is the list of bulletins and warnings issued by ACWCs/CWCs for their respective areas of responsibility:

1. Sea area bulletins for ships plying in High Seas.
2. Coastal weather bulletins for ships plying in coastal waters.
3. Bulletins for Global Maritime Distress and Safety System (GMDSS). Broadcast through Indian Coastal Earth Stations.
4. Bulletins for Indian Navy.
5. Port Warnings.
6. Fisheries Warnings.
7. Four stage warnings for Central and State Govt. Officials.
8. Bulletins for broadcast through AIRs for general public.
9. Warning for registered users.
10. Bulletins for press.
11. Warnings for Aviation (issued by concerned Aviation Meteorological Offices).
12. Bulletins for ships in the high seas through Navtex Coastal Radio Stations.

The cyclone warnings are issued to state government officials in four stages. The **First Stage** warning known as **"PRE CYCLONE WATCH"** issued 72 hours in advance contains early warning about the development of a cyclonic disturbance in the north Indian

Ocean, its likely intensification into a tropical cyclone and the coastal belt likely to experience adverse weather. This early warning bulletin is issued by the Director General of Meteorology himself and is addressed to the Cabinet Secretary and other senior officers of the Government of India including the Chief Secretaries of concerned maritime states.

The **Second Stage** warning known as **"CYCLONE ALERT"** is issued at least 48 hrs in advance of the expected commencement of adverse weather over the coastal areas. It contains information on the location and intensity of the storm likely direction of its movement, intensification, coastal districts likely to experience adverse weather and advice to fishermen, general public, media and disaster managers. This is issued by the concerned ACWCs/CWCs and CWD at HQ.

The **Third Stage** warning known as **"CYCLONE WARNING"** issued at least 24 hours in advance of the expected commencement of adverse weather over the coastal areas. Landfall point is forecast at this stage. These warnings are issued by ACWCs/CWCs/and CWD at HQ at 3 hourly interval giving the latest position of cyclone and its intensity, likely point and time of landfall, associated heavy rainfall, strong wind and storm surge alongwith their impact and advice to general public, media, fishermen and disaster managers.

The **Fourth Stage** of warning known as **"POST LANDFALL OUTLOOK"** is issued by the concerned ACWCs/CWCs/and CWD at HQ at least 12 hours in advance of expected time of landfall. It gives likely direction of movement of the cyclone after its landfall and adverse weather likely to be experienced in the interior areas.

Different colour codes as mentioned below are being used in since post monsoon season of 2006 the different stages of the cyclone warning bulletins as desired by the National Disaster Management.

Stage of warning	**Colour code**
Cyclone Alert	**Yellow**
Cyclone Warning	**Orange**
Post landfall out look	**Red**

During disturbed weather over the Bay of Bengal and Arabian Sea, the ports likely to be affected are warned by concerned ACWCs/CWCs by advising the port authorities through port warnings to hoist appropriate Storm Warning Signals. The Department also issues **"Fleet Forecast"** for Indian Navy, Coastal Bulletins for Indian coastal areas covering up to 75 km from the coast line and sea area bulletins for the sea areas beyond 75 km. The special warnings are issued for fishermen four times a day in normal weather and every three hourly in accordance with the four stage warning in case of disturbed weather.

The general public, the coastal residents and fishermen are warned through State Government officials and broadcast of warnings through All India Radio and Doordarshan telecast programmes in national and regional hook-up.

The format of Cyclone Warning bulletins issued by IMD at national level has been made more comprehensive for the use of Disaster Managers in view of the recent introduction of graphical warning products.

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The general public, the coastal residents and fishermen are warned through State Government officials and broadcast of warnings through All India Radio and Doordarshan telecast programmes in national and regional hook-up. The SMS is also sent to general public, farmers, fisherment and the disaster managers at central, state and district levels

1.3.4.3 Cyclone Warning Dissemination

Cyclone warnings are disseminated through a variety of communication media, such as, radio, television, print media, telephones, fax, telex, telegrams, police, wireless network. A specially designed Cyclone Warning Dissemination System (CWDS) which works via the INSAT Satellite provides area-specific service even when there is a failure of conventional communication channels. A set of 250 analog and 100 digital CWDS receivers have been employed in vulnerable coastal areas in the east and west coast. Steps are being taken for introduction of shortly for 500 new CWDS (Cyclone Warning Dissemination Systems), which are based on DTH concept through cable network.

1.3.4.4. Specific objectives

1.3.4.4.1. Automatic generation and dissemination of warning & advisory bulletins

The possibility of automation in generating the bulletins through a suitable software whereby several different bulletins which are focused towards the needs of specific groups such as fishermen, shipping, AIR, press, port etc. is being pursued by Cyclone Warning Division at New Delhi.

1.3.4.4.2. Common Alert Protocol (CAP)

Guidelines of implementation of Common Alert Protocol (CAP) have been received from WMO and India Meteorological Department (IMD) taken action for implementation of CAP with respect to cyclone.

1.3.4.4.3. Coastal hazard analysis

Cyclone Hazard Maps for coastal zones is made available on IMD Website.

1.3.4.4.4. Last mile connectivity

Efforts are on to increase the last mile connectivity through National Cyclone Risk Mitigation Project (NCRMP), initially under implementation in Odisha and Andhra Pradesh. It will be subsequently extended to all coastal states

1.3.4.5 On-going Projects

1.3.4.5.1 FDP on landfalling cyclones over the Bay of Bengal

This project is continuing since 2008 to demonstrate the performance of various numerical models. It has helped in improving the SOP for monitoring and prediction as well as forecast accuracy.

1.3.4.5.2. TC Wind

A project on development and execution of a software tool **TCWIND** - for depicting winds associated with 43 Tropical Cyclones over North Indian Ocean during 2000-2010 (time series of maximum sustained wind speed, vertical wind shear, tangential and radial velocities) based on IMD's best track data and 6-hrly NCEP FNL data is in progress.

1.3.4.5.3. Research on diabatic heat source and moisture sink associated with rapid intensification of north Indian ocean cyclones is being carried out.

1.3.4.5.4. ***Cyclone eAtlas-IMD***

Cyclone eAtlas – IMD, a software for generation of tracks and statistics of cyclones and depressions over the North Indian Ocean was brought out in CD form by IMD during 2008 and subsequently hosted in the web at the URL: www.rmcchennaieatlas.tn.nic.in. The database for the software for 201 updated and uploaded in the web. It is also sent to all buyers of the CD every year.

1.3.4.5.5. Statistical prediction of seasonal cyclonic activity over the North Indian Ocean

An experimental outlook on the seasonal cyclonic activity over the North Indian Ocean for the period October-December Efforts are on for improving the prediction model.

1.3.4.5.6. Experimental efforts are on for **Cyclone Intensity and Track prediction based on WRF model**. Track and Intensity predictions were generated on real time basis during October-December 2014, the chief cyclone period for the North Indian Ocean.

1.3.4.6 Disaster Management

1.3.4.6.1 Institutional and Policy Framework

The institutional and policy mechanisms for carrying out response, relief and rehabilitation have been well-established since Independence. These mechanisms have proved to be robust and effective in so far as response, relief and rehabilitation are concerned.

At the national level, the Ministry of Home Affairs is the nodal Ministry for all matters concerning disaster management. The Central Relief Commissioner (CRC) in the Ministry of Home Affairs is the nodal officer to coordinate relief operations for natural disasters. The CRC receives information relating to forecasting/warning of a natural calamity from India Meteorological Department (IMD) or from Central Water Commission of Ministry of Water Resources on a continuing basis. The Ministries/ Departments/Organizations concerned with the primary and secondary functions relating to the management of disasters include:

India Meteorological Department, Central Water Commission, Ministry of Home Affairs, Ministry of Defence, Ministry of Finance, Ministry of Rural Development, Ministry of Urban Development, Department of Communications, Ministry of Health, Ministry of Water Resources, Ministry of Petroleum, Department of Agriculture & Cooperation. Ministry of Power, Department of Civil Supplies, Ministry of Railways, Ministry of Information and Broadcasting, Planning Commission, Cabinet Secretariat, Department of Surface Transport, Ministry of Social Justice, Department of Women and Child Development, Ministry of Environment and Forest, Department of Food. Each Ministry/Department/Organization nominate their nodal officer to the Crisis Management Group chaired by Central Relief Commissioner. The nodal officer is responsible for preparing sectoral Action Plan/Emergency Support Function Plan for managing disasters.

1.3.4.6.2 National Crisis Management Committee (NCMC):

Cabinet Secretary, who is the highest executive officer, heads the NCMC. Secretaries of all the concerned Ministries /Departments as well as organizations are the members of the Committee The NCMC gives direction to the Crisis Management Group as deemed necessary. The Secretary, Ministry of Home Affairs is responsible for ensuring that all developments are brought to the notice of the NCMC promptly. The NCMC can give directions to any Ministry/Department/Organization for specific action needed for meeting the crisis situation.

1.3.4.6.3. Crisis Management Group:

The Central Relief Commissioner in the Ministry of Home Affairs is the Chairman of the CMG, consisting of senior officers (called nodal officers) from various concerned Ministries. The CMG's functions are to review every year contingency plans formulated by various Ministries/Departments/Organizations in their respective sectors, measures required for dealing with a natural disasters, coordinate the activities of the Central Ministries and the State Governments in relation to disaster preparedness and relief and to obtain information from the nodal officers on measures relating to above. The CMG, in the event of a natural disaster, meets frequently to review the relief operations and extend all possible assistance required by the affected States to overcome the situation effectively. The Resident Commissioner of the affected State is also associated with such meetings.

1.3.4.6.4 Control Room (Emergency Operation Room):

An Emergency Operations Centre (Control Room) exists in the nodal Ministry of Home Affairs, which functions round the clock, to assist the Central Relief Commissioner in the discharge of his duties. The activities of the Control Room include collection and transmission of information concerning natural calamity and relief, keeping close contact with governments of the affected States, interaction with other Central Ministries/Departments/Organizations in connection with relief, maintaining records containing all relevant information relating to action points and contact points in Central Ministries etc., keeping up-to-date details of all concerned officers at the Central and State levels.

1.3.4.6.5 National Disaster Management Authority (NDMA)

About 8% of the area in the country is prone to cyclone-related disasters. Recurring cyclones account for large number of deaths, loss of livelihood opportunities, loss of public and private property and severe damage to infrastructure, thus seriously reversing developmental gains at regular intervals.

Broad-scale assessment of the population at risk suggests that an estimated 32 crore people, which accounts for almost a third of the country's total population, are vulnerable to cyclone related hazards. Climate change and its resultant sea-level rise can significantly increase the vulnerability of the coastal population.

As mandated by Disaster Management Act, 2005, the Government of India (GoI) created a multi-tiered institutional system consisting of the National Disaster Management Authority (NDMA) headed by the Prime Minister, the State Disaster Management Authorities (SDMAs) by the respective Chief Ministers and the District Disaster Management Authorities (DDMAs) by the District Collectors and co-chaired by Chairpersons of the local bodies. These bodies have been set up to facilitate a paradigm shift from the hitherto relief centric approach to a more proactive, holistic and integrated approach of strengthening disaster preparedness, mitigation and emergency response.

1.3.4.6.6 Guidelines for the Management of Cyclones

The NDMA has prepared Guidelines for the Management of Cyclones to assist ministries and departments of GoI and state governments to prepare their DM plans. The guidelines are presented in nine chapters as detailed below:

i. Chapter 1 provides an introductory overview that reflects the risk and vulnerability of the country to cyclones, including the dimensions and magnitude of the problem.
ii. Chapter 2 discusses the Early Warning Systems (EWS) for cyclones. In this chapter, the present status of EWSs has been discussed and the gaps have been identified. Requirement to bring them up to international standards and making them state-of-the-art systems has been recommended.
iii. Chapter 3 deals with the present status of Warning Communication and Dissemination, its gaps and future improvements required towards making it fail-proof and modern.
iv. Chapter 4 covers structural measures for preparedness and mitigation, covering cyclone shelters, buildings, road links, culverts and bridges, canals, drains, saline embankments surface water tanks, cattle mounds and communication/power transmission networks.
v. In Chapter 5, important aspects of the management of coastal zones and its relevance to CDM, including some other non-structural mitigation options have been presented. This chapter discusses issues related to coastal zone management, sustainability of coastal resources, bioshields, coastal flood plain management, coastal erosion, natural resources management, etc.
vi. Chapter 6 deals with various aspects of awareness generation related to CDM as an important preparedness measure.
vii. Chapter 7 covers Disaster Risk Management (DRM) issues, risk assessment and vulnerability analysis, hazard zoning and mapping, data generation, including the use of GIS tools, and capacity development.
viii. Chapter 8 deals with CDM-related response and relief strategies. A detailed account of several issues related to effective response such as response platforms, linking risk knowledge with response planning, evolving disaster response capabilities, etc., is brought out in this chapter.
ix. In Chapter 9, guidelines and implementation strategies have been discussed.
x. Salient initiatives recommended for implementation as part of the National Guidelines for Management of Cyclones are listed for undertaking action by various relevant Departments.
xi. The detail Guideline is hoisted in the NDMA website.

1.3.4.6.7. Current Status

(i) Meetings related to cyclone preparedness and disaster management conducted by the State Govt. departments are regularly attended by IMD officers to provide necessary briefings and inputs.
(ii) Frequent lectures on Disaster Preparedness and Mitigation are delivered to educate the State Govt. officials and NGOs.
(iii) Exhibits on Statistics on frequencies of landfalling Tropical Cyclones over the coastal belts of North Indian Ocean, Cyclone Warning procedures employed by IMD,

Damages caused due to landfalling cyclones etc. are prepared every year with updated data and displayed in the meteorological exhibition conducted during the WMO Day, National Science Day and Indian Science Congress.

(iv) Exhibits are also supplied to schools and other academic/ govt. institutions for display during scientific programmes. IMD officials also participate in such exhibitions.

1.3.4.6.8. National Disaster Response Force (NDRF)

Two national calamities in quick succession in the form of Orissa Super Cyclone (1999) and Gujarat Earthquake (2001) brought about the realization of the need of having a specialist response mechanism at National Level to effectively respond to disasters. This realization led to the enactment of the DM Act on 26 Dec 2005. The NDMA was constituted to lay down the policies, plans and guidelines for disaster management.

The DM Act has made the statutory provisions for constitution of National Disaster Response Force (NDRF) for the purpose of specialized response to natural and man-made disasters. Accordingly, in 2006 NDRF was constituted with 08 Bns (02 Bn each from BSF, CRPF, ITBP and CISF). As on date NDRF is having strength of 10 Bns. Each NDRF Bn consists of 1149 personnel. Union cabinet has also approved the conversion/up-gradation of 02 Bns from SSB.

The force is gradually emerging as the most visible and vibrant multi–disciplinary, multi-skilled, high-tech, stand alone force capable of dealing with all types of natural and man-made disasters.

The DM Act, 2005 envisages a paradigm shift from the erstwhile response centric syndrome to a proactive, holistic and integrated management of disasters with emphasis on prevention, mitigation and preparedness. This national vision inter alia, aims at inculcating a culture of preparedness among all stakeholders.

NDRF has proved its importance in achieving this vision by highly skilled rescue and relief operations, regular and intensive training and re-training, capacity building & familiarization exercises within the area of responsibility of respective NDRF Bns, carrying out mock drills and joint exercises with the various stakeholders.

Vision of NDRF is to emerge as the most visible and vibrant multi-disciplinary, multi-skilled, high-tech force capable to deal with all types of natural as well as manmade disasters and to mitigate the effects of disasters.

1.3.4.6.8.1 Role and Mandate of NDRF

- Specialized response during disasters
- Proactive deployment during impending disaster situations
- Acquire and continually upgrade its own training and skills
- Liaison, Reconnaissance, Rehearsals and Mock Drills
- Impart basic and operational level training to State Response Forces (Police, Civil Defence and Home Guards)
- Vis-à-vis Community- All NDRF Bns are actively engaged in various:
- Community Capacity Building Programme
- Public Awareness Campaign
- Exhibitions : Posters, Pamphlets, literatures

1.3.4.6.8.2 Unique Force

- The only dedicated disaster response force of the world.
- The only agency with comprehensive response capabilities having multi-disciplinary and multi-skilled, high-tech, stand alone nature.
- Experienced paramilitary personnel specially trained and equipped for disaster response.
- Capabilities for undertaking disaster response, prevention, mitigation and capacity building

1.3.4.6.9 National Institute of Disaster Management (NIDM)

- The National Institute of Disaster Management (NIDM) was constituted under an Act of Parliament with a vision to play the role of a premier institute for capacity development in India and the region. The efforts in this direction that began with the formation of the National Centre for Disaster Management (NCDM) in 1995 gained impetus with its redesignation as the National Institute of Disaster Management (NIDM) for training and capacity development. Under the Disaster Management Act 2005, NIDM has been assigned nodal responsibilities for human resource development, capacity building, training, research, documentation and policy advocacy in the field of disaster management.
- Both as a national Centre and then as the national Institute, NIDM has performed a crucial role in bringing disaster risk reduction to the forefront of the national agenda. It is our belief that disaster risk reduction is possible only through promotion of a "Culture of Prevention" involving all stakeholders. We work through strategic partnerships with various ministries and departments of the central, state and local governments, academic, research and technical organizations in India and abroad and other bi-lateral and multi-lateral international agencies.
- NIDM is proud to have a multi-disciplinary core team of professionals working in various aspects of disaster management. In its endeavour to facilitate training and capacity development, the Institute has state-of-the-art facilities like class rooms, seminar hall, a GIS laboratory and video-conferencing facilities etc. The Institute has a well-stocked library exclusively on the theme of disaster management and mitigation. The Institute provides training in face-to-face, on-line and self-learning mode as well as satellites based training. In-house and off-campus face-to-face training to the officials of the state governments is provided free of charge including modest boarding and lodging facilities.
- NIDM provides technical support to the state governments through the Disaster Management Centres (DMCs) in the Administrative Training Institutes (ATIs) of the States and Union Territories. Presently NIDM is supporting thirty such centres. Six of these centres are being developed as Centres of Excellence in the specialised areas of flood risk management, earthquake risk management, cyclone risk management, drought risk management, landslides risk management and management of industrial disasters. Eleven larger states (Andhra Pradesh, Bihar, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, Tamil Nadu, Uttar Pradesh, West Bengal and Odisha) have been provided with additional centres to cater their needs in this area.

- NIDM hosts the SAARC Disaster Management Centre (SDMC) and works as its national focal point.
- The vision is to create a Disaster Resilient India by building the capacity at all levels for disaster prevention and preparedness.

1.3.4.6.10. Common Alert Protocol (CAP)

Guidelines of implementation of Common Alert Protocol (CAP) have been received from WMO and India Meteorological Department (IMD) already is taken action for implementation of CAP with respect to cyclone, thunderstorm & earthquake. Initially it has introduced Google Alert for cyclones from 2014.

1.3.5. Maldives

Maldives Meteorological Service followed the Standard Operating Procedure (SOP) and issued 216 WHITE Alerts, 15 YELLOW Alerts 2015 Cyclone Season.

1.3.6. Pakistan

PMD has a state-of-the-art National Seismic Monitoring and Tsunami Early Warning Centre at Karachi and backup centre at Islamabad for monitoring of earthquakes and associated tsunamis. The centre is supported by a network of 30 remote seismic monitoring stations located throughout the country which are continuously recording the earthquake activity in the region. PMD issues SMS to media and other stakeholders immediately about the location, magnitude, depth, times and shock-wave information. Such SMS cover all earthquakes greater than magnitude 2 on Richter scale and earthquake information is disseminated within 3-minutes of the occurrence of earthquake through SMS to media and other concern stakeholders/government functionaries.

PMD installed a Siren System for satellite based tsunami early warning for the communities residing at the coastal cities of Pasni and Gwadar in Balochistan province. Both cities were suffered by a tsunami in November, 1945 and approximately 4,000 precious lives were lost in. The Siren System for tsunami early warning is the donation from Oxfam Great Britain and UNDP. He further informed that in the past Pakistan nation has suffered severe life and economic losses due to devastating earthquakes and tsunami. To mitigate these hazards in Pakistan, the Islamic Development Bank (IDB), Kingdom of Saudi Arabia in collaboration with Marmara Research Center (MRC), Turkey has sketched out “Reverse Linkage Project on Earthquake Seismological Research between MRC and PMD” to enhance the capabilities of Pakistan in the field of earthquake, tsunami, and tectonics of the earthquake prone areas of the country. The total cost of the project is PKR 101 million through which IDB and MRC share is 78% while Government of Pakistan’s share is around 23%. This project is for the study of Makran Subduction zone and the tectonics of southern Baluchistan. Targets to be achieved under this project are given as under:

(a). Up gradation of earthquake analysis system of PMD, i.e. SeisComP3 which also works as a tsunami early warning system. The newer version will replace the old one installed at Islamabad and Karachi.

(b). Deployment of five (05) Global Positioning System (GPS) stations for Makran coast of Balochistan province and one set of equipment for backup.

(c). Deployment of five new seismic monitoring stations for Balochistan province and one set of equipment for backup.

(d). Installation of three (03) sets of site classification measurement systems for risk assessment.

The completion of the project would facilitate PMD to further enhance its capacities in the field of seismological research, help to mitigate seismic risk through provision of improved seismological information and thus significantly contribute to the safety of lives and property of the people of Pakistan in the wake of geophysical disasters. He further informed that after the strong Hindu Kush earthquake of M8.1 on October 28, 2015 the National Seismic Monitoring Centre of PMD, started investigating the reasons of increasing frequency of earthquake around the country. A comprehensive report was formulated as an outcome of the research contributed by the scientists of Seismic Monitoring Centre. In addition, after this strong earthquake, PMD and Geological Survey of Pakistan (GSP) responded to National Disaster Management Authority (NDMA)'s request and carried out Micro Zonation of Pakistan.

1.3.7. Sri Lanka

The disaster Management Centre (DMC) one of the coordinating and implementation body under the Ministry of Disaster Management. It involves in disseminating the warnings and advisories from the technical agencies to the grass root level, conducting public and awareness programmes, disaster mitigation activities, research & development activities, emergency operation activities in 24 x 7 basis and preparedness and planning activities for prevention of the disasters with the respective agencies to create a safer culture in Sri Lanka. District disaster preparedness plans have been completed for all 25 districts plans, 175 divisional plans and 2000 plans for Grama Niladhari (lowest level in the administration) divisional level plans were completed up to now. More than 200 mock drills were also completed in 2015 (Including the National Drills). Cyclone hazard mapping has been completed with technical support from Department of Meteorology and financial support from UNDP. National safety day commemorations was well performed on 26th December 2015 around the country concentrating preparedness activities and public awareness.

1.3.8. Thailand

The Department of Disaster Prevention and Mitigation (DDPM) of Thailand is the responsible agency for imposing and implementing program policy, formulating operational guidelines and establishing criteria on disaster management, In addition, DDPM organizes and conducts training activities covering all aspect of disaster management by collaboration with local and international organizations. The Cabinet has endorsed the National Disaster Prevention and Mitigation plan 2015, it is the 2nd Disaster Management Plan and undergone a participatory planning process, where related sectors were engaged, including public, private and civil society. The above mentioned Plan has enforced related sectors of all levels to implement the plan, to develop their own action plan and to incorporate projects and programmes on disaster risk management into their annual plan, and particularly for the Budget Bureau, concerned agencies and local governments to give priority to projects/programmes on disaster risk reduction, emergencies response and recovery in a sustained manner. The improvement and evolution of this National Management Plan is derived and gathered from lessoned learned from global, regional, national and local level and the trend of future disaster.Department of Disaster Prevention and Mitigation (DDPM) has assigned Disaster Management Center as dissemination center for providing early warning to the public, after receiving severe storm forecasting from Thai Meteorological Department or Regional Meteorological Center, Disaster Management Center will inform disseminate warning messages to DDPM provincial offices in risk area by LINE application or Fax or radio channels. DDPM provincial office will report the warning messages to the Governor, Province Public Relation Office and risk prone community via telephone or fax to prepare for evacuation.

Additionally, Ministry of Interior by DDPM under the organizational structure of National Emergency Operation Headquater/ Incident Command Center, Emergency Support Function 5, Emergency Management, the duties of monitoring, providing early warning messages to the public and related agencies and preparing for evacuation are under DDPM, MOI.

The Cooperation with agency concerned, DDPM has 76 provincial offices and 18 Regional Centers, they are working closely with community level and other government organizations to provide victim assistance and share data and information for disaster management. (included typhoon and storm forecasting data sharing with Thai Met)

During normal situation, DDPM by Disaster Prevention Promotion Bureau cooperates with DDPM provincial offices to provide CBDRM Training Approach (Community Base Disaster Risk Management) to support risk prone communities to handle with disaster during emergency. The community people know and understand their risks better than people who live outside prone areas.

The main challenge is Thailand has more than 10,000 risk communities from land slide and flash flood, according to the constraint of budget, it is difficult to provide CBDRM training to all risk areas in a short period of time.

In order to integrate effectively early warning systems to vulnerable communities, DDPM has promoted and developed CBDRM approach for risk communities by providing training them how to prepare and respond to disasters properly. The CBDRM activities include conduct risk assessment, prepare risk map, set up warning system for community etc.

DDPM has recognized the importance of socio-economic impact in Macro sector which also affected by large scale disaster, therefore, DDPM has cooperated with, NESDB JICA and ADPC to promote BCP (Business Continuity Plan) to private sector and SMEs. BCP can support private sector and SMEs work smoothly while disaster occurs and reduce economic lost from disaster. In addition, in normal situation we conduct exercises regularly with other government organizations and related sectors to ensure the appropriate preparedness.

1.4 TRAINING

1.4.1. ACTIVITIES OF THE WMO

The Panel noted the training events and workshops which were organized during the intersession for the benefit of its Members. Since its last session, the Panel had benefited from education and training activities of WMO through the provision of attachments, relevant training courses, workshops, and the provision of advice and assistance to Members.

- Attachment Training
  RSMC Tokyo, 22-31 July 2015
- WMO Training Workshop on TC Forecasting and Warnings for PTC Region
  New Delhi, India , 3 – 14 August 2015
- WMO International Training Workshop on Tropical Cyclone Forecasting and Warning
  Nanjing, China, 7 - 11 December 2015

The Panel noted the forthcoming training events planned for 2016, and the Members were encouraged to make maximum benefit of attachments, training seminars, workshops and courses to be organized or co-sponsored by WMO.

- Attachment Training
  - *RSMC Tokyo (15-26 August 2016)*
  - *RSMC New Delhi (19-30 September 2016)*

The Panel has constituted an expert group to prepare a draft training plan for the next Panel session.

PTC training plan to support the Coordinated Technical Plan as follows:

a) Expert Group to produce a prioritized list of training needs and opportunities of PTC Members through a survey and advise WMO for reporting, planning and implementation purposes.
b) The plan to be submitted in the next session of WMO/ESCAP PTC.
c) WMO to provide the relevant documents to the expert group and PR of each member country.

Details are given below.

a) An expert group of members (Bangladesh, India, Maldives & Sri Lanka) as constituted by 43rd WMO/ESCAP PTC session to prepare draft training plan from 2017-2019. Expert Group to produce a prioritized list of training needs and opportunities of PTC Members through a survey and advise WMO for reporting, planning and implementation purposes. The plan to be submitted in the next session of WMO/ESCAP PTC. WMO to provide the relevant documents to the expert group and PR of each member country.
b) Whilst there are many opportunities available for Panel members to access education and training opportunities, the offers are not always well coordinated and not all members may be aware of the opportunities. Developing and then maintaining and communicating a training plan to complement the agreed Coordinated Technical plan is one way to ensure that the capacity of all Panel members increases. The training plan would also provide a means to identify the training gaps and look for options to address them.
c) The training plan could include seeking information on:

- the types and ranges of TC services provided by the Panel members
- the number of personnel involved in developing, delivering and communicating these services. It may be best to break these personnel numbers down into topic groupings as not all staff may be doing the same types of activities.
- types of systems used by the forecasters for their work
- whether the TC services are based upon the RSMC forecasts or are developed nationally (interpretative vs full forecasting capacity)
- coordination mechanisms and roles with the national emergency authorities (to see what common roles may exist)

- what education and training opportunities may exist and what is being used (secondments to RSMC or other advanced centre, twinning or option for staff from one country to travel to another to assist in training, face-to-face courses, fellowships, online training (as a course or stand-alone self-directed training), participation in regular online meetings or weather briefings such as those offered by the WMO Virtual Laboratory for Satellite Meteorology)
- what financial or other resources may be available to support training (for example use of the COMET MetEd website https://www.meted.ucar.edu/training_detail.php)
- the potential for the proposed TC forecaster competency framework to assist in improving the effectiveness of training courses provided to Panel members.

1.4.2. ACTIVITIES OF ESCAP

In 2015, ESCAP supported 4 experts from PTC and TC to participate in the training organized by RSMC, New Delhi for forecasters in August, 2015. ESCAP also supported 4 experts from PTC to participate in the TC Roving Seminar in November 2015. It further encouraged RSMC, Tokyo to provide training to PTC members, and coordinated with RSMC, Tokyo to invite 6 PTC members to be trained in Japan.

1.4.3. BANGLADESH

Tropical Cyclone forecasters have been sent to RSMC New Delhi for attachment training. Forecasters are encouraged to pursue research work on track prediction of Tropical Cyclone and storm surge.

1.4.4. India

The Human Resource Development has been one of the prime thrust areas of capacity building in IMD to keep pace with the latest trends in weather monitoring and forecasting. Meteorological Training Institute (MTI) at IMD Pune acts as a WMO recognised regional training centre. Like previous years, MTI Pune conducted various training programmes in 2015. The course curricula of various training courses have been modified keeping in view the latest developments.

1.4.4.1 Regular Courses on General Meteorology

S.No.	Departmental/Non Departmental courses	Duration	Training centres	Eligibility Criteria
1.	Advanced Met. Training Course (Non-Departmental)	1 Year	Pune	B.Sc*. (with Physics or Maths as main subject) /M.Sc./B.E./ B.Tech.
2.	Forecasters Training course	6 months	Pune	B.Sc. (with Physics or Math as main subject) and after successful completion of Intermediate Met. Training course
3.	Intermediate Training course including one month on the Job training.	3 months	Pune, Delhi, Kolkatta & Chennai	B.Sc. (with Physics or Maths as main subject) after successful completion of

			centres.	Basic Met. Training course.
4.	Integrated Meteorological Training course.	4 months	Pune , Delhi, Chennai and Kolkata	Fresh recruited Scientific Asst.with B.Sc.(Phy., Math/ BE/B. Tech. qualification
5	LA's Modular Course	2 Months	Delhi & Kolkotta.	Departmental Met. Attendant who have passed SSC and working in same cadre for 5 years

1.4.4.2 Other Trainings

- Training Programs, Seminars and Workshops are conducted to operational forecasters for improvement of forecast skills in real-time forecast. Capacity Development of personnel from IMD, NCMRWF, IAF, Indian Navy, Coast Guard, NDMA, Indian Army, ICAR, DRDO, Universities, Research Institutes and other National/International Organizations was undertaken.
- Imparted training from 53 countries in the area of instrument, cyclones, climate, forecasting and general meteorology.
- In addition, RSMC New Delhi conducted its regular cyclone training programme.
- Various other divisions of IMD such as Satellite Meteorological Division, Radar Division and NWP Division conducted training programmes in their respective areas for national and international participants.
- E-learning in training programme has been introduced for some courses of IMD. Initiative is being taken up to introduce distance learning through virtual classroom facilities in IMD's training programme.
- Two refresher courses viz. on tropical cyclones and climate science have been organized in 2015.

1.4.4.3 Future Plans:

- Five Advanced Refresher Courses viz. Aviation Meteorology, Radar Meteorology, Radar Technology, Communication and IS and NWP have been planned to be conducted during 2016-17.
- To upgrade the infrastructure of training institute & Trainees Hostel, action is in progress.
- Revision of the syllabus /Course contents of the different training courses is in progress.
- e-Learning method in training programme is already introduced by MTI. Action towards introduction of distance learning in the IMD's training programs by the provision of virtual class room facilities is already initiated. Under this proposal, provision is also there to share the digital content of the lectures in broadcast mode between centres through internet based software.
- One year ab-initio training for Group A officers (direct recruit) of the department to be conducted in this year.
- Action towards publication of lecture notes in respect of Integrated Meteorological Training Course is in progress.

1.4.5. Maldives

4.6.4 The representative of Maldives informed the panel that to build the capacity of MMS further and in accordance with the mandate and action plan, we urgently need to train its personnel in DWR, Aeronautical forecasting, Satellite Met, WRF/ WAM, data assimilation, climate, tsunami propagation and storm-surge modeling.

1.4.6. Oman

The 7th WMO Centre of Excellence in Oman has conducted the 11th session of satellite application course (SAC) for Middle East countries in cooperation with Eumetsat.

Workshop/Seminar/Training/Research Course (2015)	Country	No. of Persons
PhD. In Dust Modelling	Australia	1
EUMETSAT Satellite Application Course	Oman	15
Climatological database CLDB	Slovakia	1
Aeronautical Meteorological Forecasting	China	2
Tropical cyclone Forecasting Course	India	2
Marine Forecasting	South Africa	2
Tsunami	Germany	6
Observer Training	India	18
Training in McIDAS-V	Oman	7
Weather Radar	Oman	8
Basics in linux	Oman	5

1.4.7. Pakistan

For the capacity building of PMD in the field of meteorology, hydrology, seismology, climate sciences and related disciplines maximum efforts are being made for seeking higher education and training opportunities abroad for PMD scientists in these fields since 2006. So far, thirty-two (32) officers have joined back to PMD after completion of their higher studies (MS/PhD) from some reputeable institutions in UK, Canada, Norway, China and Thailand. During 2015, one scinetist proceeded to Canada for Post-Doc in Meteorology from Environemnt Canada. While two (02) scinetists proceeded abroad one for China and other for Saudi Arabia for doing Ph.D in Meteorology at the Institute of Tibetan Plateau Research, Chinese Academy of Sciences, China under fellowship grant and at the King Abdulaziz University (KAU), Jeddah, Saudi Arabia under award of fellowship by KAU. In addition, one scientist proceeded to Japan for doing M.S in Hydrology & Flood related Disaster Management at the International Centre for Water Hazard and Risk Management (ICHARM) Japan and one scientist proceeded to Nanjing University of Information Science and Technology (NUIST) for doing MS (Meteorology) under scholarship offered by the NUIST-China. Beisdes this one more scientist proceeded abroad for doing 3-years M.Sc (Hydrology) at Russian State Hydrometeorlogical University, St. Petersburg, Russian Federation under award of WMO Fellowship.

While four (04) PMD officers have been doing their Ph.D (Meteorology) at the Chinese Academy of Sciences (CAS), China since 2013. These scientists have been awarded scholarship by the CAS for their PhD program and are expected to return by the end of year 2016. Two (02) more officers are undertaking their Ph.D in Meteorology and Hydrometeorology at the University of Hamburg, Germany and the University of Arizona,

USA respectively sience 2013 under scholarship program. In addition, three (03) officers have been doing their 3-years Ph.D Meteorology program at KAU, Saudi Arabia since 2014.
During 2015, four (04) PMD scientists joined back after completion of their Ph.D (Meteorology) from China. One (01) more scientist joined back to PMD after completion of M.S. in Hydrology and Flood related Disaster Management from International Centre for Water Hazard and Risk Management (ICHARM), Japan under generous support by JICA/Government of Japan while one scientist is still doing such program in Japan.
During 2015, around 50 fellowships were availed by PMD scientists for attending short-term trainings/ workshops/ seminars abroad. These fellowships were offered mainly by WMO, ICIMOD, ICTP, IOC-UNESCO, CMA, JMA, JICA, JAXA, NARBO, UNESCO, UN-ESCAP, APCC Korea etc.

1.4.7.1 Training of Met. Personnel at PMD's Institute of Meteorology and Geophysics (IMG), Karachi:

During 2015-2016, various regular and special courses on meteorology were also conducted at IMG, Karachi for in-service Met personnel of PMD as well as for Met officials from other relevant organizations including Met branch of Pakistan Air Force and Navy. These courses include Initial and Preliminary Meteorology Courses (WMO BIP–MT), Basic Forecasting Course (WMO BIP–M) and others.

1.4.7.2. Training to the Met Officials from neighbouring Countries:

PMD started to extend its training facilities to the NMHSs of the neighbouring countries for their capacity building through WMO Voluntary Cooperation Programme in 2008. For this purpose, special Preliminary Meteorology Courses (BIP-MT) were conducted in 2008, 2009 and 2010 at PMD's Institute of Meteorology & Geophysics (IMG), Karachi in which 31 Met Officials from Bangladesh, Bhutan, Maldives, Myanmar, Nepal and Sri Lanka got benefitted from these courses.
In 2015, upon request of Department of Meteorology, Sri Lanka, three (03) Met personnel were imparted training at IMG, Karachi. Air travel and stipend of participants was borne by Govt. of Sri Lanka and PMD provided waiver of tuition fee and free accommodation in hostel facilities of IMG Karachi. Similarly in February 2016, three (03) more Met officials from Department of Meteorology, Sri Lanka have been enrolled in Preliminary Meteorology Course at IMG Karachi.

1.4.8. Sri Lanka

Two meteorologists are currently receiving post graduate training at University of Phillipines and Ewha Women University, South Korea under the fellowship of WMO .The following short term training workshop/seminars organized/cosponsored by WMO were attended by the scientific staff of the department.

- 41st Session of the IPCC, Kenya, 24-27 Feb 2015
- South-Asia drought monitoring system, Climate Outlook and Water User Forum, Bangladesh, 20-23 Apr 2015
- Forty –second Session of ESCAP/WMO PTC & 47th session on Tropical Cyclone, Thailand, 9-13 Feb 2015
- ESCAP/WMO Typhoon Rowing Seminar, Lao PDR, 4-6 Nov 2015

- Severe Weather forecasting Demonstration Project (SWEDP) – Training WS on Severe Wx Forecasting & Warning Services, Thailand, 14-25 Sep 2-15
- Sixth Session of the SASCOF & Forum for Water sector in South-Asia, Bangaladesh, 19-23 Apr 2015
- Capacity Building work shop on Data Rescue, Tanzania, 9-14Nov 2015
- Win SASCOF-1 meeting, India, 14-15 Oct 2015
- Severe Weather forecasting Demonstration Project (SWEDP) – Training WS on Severe Wx Forecasting & Warning Services one week PWS training, Thailand, 14-25 Sep 2-15
- Third WMO/WWRP Monsoon Heavy Rainfall Workshop, India, 22-24 Sep 2015
- Course on Instrument maintenance and Calibration, RA II countries, Nanjing, China, 2-27 Nov 2015
- 5th International Workshop of Port Meteorological Officers, Chile, 2-24 July 2015

1.4.9. Thailand

Thai Meteorological Department (TMD) sent officials to attend in the trainings supported by WMO as below:

- GURME Training Workshop, 7-10 April 2015, Malaysia.
- Attachment Training at RSMC Tokyo 2015, 22 – 31 July 2015 JMA Headquarters, Tokyo Japan.
- International Training Workshop on Tropical Cyclone Forecasting, 3 – 14 August 2015, New Delhi, India.
- Training of Trainers Course on climate Field Schools (ToT on CFS) and Workshops on the Global Framework for Climate Services for Asia-Pacific Countries (GFCS Workshop), 25 – 28 August 2015,Citeko Indonesia.
- Training on Meteorological Disaster Management for Official from Developing Countries, WMO RTC Beijing, 7 – 18 September 2015.
- The Common Alerting Protocol (CAP) Jump-Start Training Session and CAP Implementation Workshop, 22, 23-24 September 2015, Rome, Italy.
- International Short-term Course on Flood Forecasting and Warning for South and Southeast Asia, 26 October – 1 September 2015, Roorkee, India.
- Fourth Capacity Building Workshop of the Data Buoy Cooperation Panel (DBCP) for the North pacific Ocean and its Marginal seas (NPOMS-4), Busan, Republic of Korea, 2-4 September 2015.
- Group Fellowship Training on Instrument Maintenance and Calibration, Nanjing, China, 2– 27September 2015.
- Training on Regional Satellite data usage, designed Specifically for satellite data users in RAII, 9,13 Nov. 2015, JMA, Tokyo, Japan, 9 – 13 November 2015.
- 8th International Workshop on Tropical Cyclones (IWTC-VIII) and 3rd International Workshop on Tropical Cyclone Landfall Processes (IWTCLP-III), 2 – 10 December 2015, Jeju, Republic of Korea.
- Training on Tropical Cyclones Forecasting and Warning, 7 – 11 December 2015, RTC Nanjing,China.

(i) During 2015, the Thai Meteorological Department (TMD) in cooperation with the World Meteorological Organization (WMO) organized a two- week Training Workshop entitled "Severe Weather Forecasting Demonstration Project (SWFDP) Regional Subproject for the Bay of Bengal and Southeast Asia Training Workshop on Severe Weather Forecasting and Warning Services" at the Thai Meteorological Department (TMD) in Bangkok from 14 to 25 September 2015,

(ii) The Thai Meteorological Department (TMD) in cooperation with the Japan International Cooperation Agency (JICA) Office in Bangkok and the Thailand International Cooperation Agency (TICA) organized a Training course on Hydrology (Advance Flood Forecasting, Flash Flood Forecasting, Remote Sensing and GIS) for the Myanmar Officials from 18 January to 17 February 2016, at TMD Headquarters, Two Staffs of RID joined the Training for WGH AOP4 on Operational system for Urban Flood Forecasting and Inundation Mapping (OSUFFIM), held in Sun Yat-Sen University Guangzhou, China, 15 November to 14 December 2015.

(iii) TMD cooperation with the Japan Aerospace Exploration Agency (JAXA) which was the qualitative precipitation estimation (QPE) from satellite to estimation rainfall, monitoring and warning, supported hydrology (the Royal Irrigation Department: RID, the Electricity Generating Authority of Thailand: EGAT, the Department of Water Resources: DWR and so all).

(iv) December 2015, 2 Staffs of RID joined the Training for WGH AOP4 on Operational system for Urban Flood Forecasting and Inundation Mapping (OSUFFIM), held in Sun Yat-Sen University Guangzhou, China.

(v)

1.4.10. Recommendations

To understand, interpret and convey the warnings correctly, a training should be held in capacity building of the users and media.

1.5 RESEARCH and publication

1.5.1. ACTIVITIES OF WMO

The Three World Weather Research Programme (WWRP) projects on tropical cyclones below had been extended to 2018:

a) North Western Pacific Tropical Cyclone Ensemble Forecast Project (NWP-TCEFP) for Typhoon Committee members covering the period 2010 to 2018 (Lead: Japan Meteorological Agency);
b) Typhoon Landfall Forecast Demonstration Project (TLFDP) covering the period 2010 to 2018 (Lead: Eastern China Regional Meteorological Center/CMA).
c) Understanding and PreDiction of Rainfall Associated with landFalling Tropical cyclones covering the period 2014-2018 (UPDRAFT) (Lead: Nanjing University)

The NWP-TCEFP is a collaborative effort between WMO and the Typhoon Committee and aims to explore the utility of ensemble forecast products through THORPEX interactive Grand Global Ensemble (TIGGE) and thus promote application of the products to the operational forecasting of tropical cyclones. It is closely linked with the TLFDP. The TLFDP is a collaborative effort with the NWP-TCEFP which had been extended to 2018 to continue its work on tropical cyclone genesis and verification of tropical cyclone forecasts and also include collaborative activities with the work of the Typhoon Committee's The Experiment on Typhoon Intensity Change in Coastal Area (EXOTICA). It is envisioned that all the above-mentioned projects will be instrumental in transferring the recent research advances to operational forecast centers in NMHSs, especially those which have been affected by the recent increase in the severity of tropical cyclone events in highly populated coastal areas. UPDRAFT in 2015 successfully held its' first project-related workshop at the Nanjing University from 30-31 November with the participation of several world-renowned tropical cyclone experts.

Plans are underway to organize the 4th International Workshop on Tropical Cyclone Landfall Processes (IWTCLP-III) and the 9th International Workshop on Tropical Cyclones (IWTC-IX) and in 2017 and 2018 respectively. The two workshops are being organized by WWRP in close collaboration with TCP. The Panel on Tropical Cyclones will be represented by the Director of RSMC New Delhi in the International Organizing Committee for IWTC-IX. Members of the Panel are urged to actively participate in the said Workshop. Operational and research meteorologists from Panel Members who will not need WMO support to participate at the IWTCLP-III and IWTC-IX should, in a timely manner, inform TCP of their intent to attend the said workshops.

The High Impact Weather (HIWeather) project kick-off meeting was held in the UK Met Office (Exeter, UK) from 25-29 April 2016. HIWeather is a ten year activity within the WWRP to promote cooperative international research to achieve a dramatic increase in resilience to high impact weather, worldwide, through improving forecasts for timescales of minutes to two weeks and enhancing their communication and utility in social, economic and environmental applications. The scope of the project is defined by the needs of users for better forecast and warning information to enhance the resilience of communities and countries in responding to a carefully selected set of hazards such as urban floods, rain-induced landslides, localized extreme winds including localized wind maxima within tropical cyclones.

1.5.2. ACTIVITIES OF ESCAP

ESCAP published the following reports, papers and technical materials related to the work of the PTC.

a) ESCAP (2015) Asia-Pacific Disaster Report 2015: Disasters without Borders – Building Resilience for Sustainable Development;
b) ESCAP (2015) Advisory note: El Nino 2015/2016 – Impact outlook and policy implications;
c) ESCAP (2016) Disasters in Asia and the Pacific: 2015 Year in Review;
d) ESCAP and SDMC (2016) Manual of Rapid Assessment for Resilient Recovery, and
e) ESCAP and RIMES (2016) Flood Forecasting and Early Warning in Transboundary River Basins: a Toolkit.

The panel noted of the following training opportunities supported by ESCAP.

a) Regional training on slow-onset disasters impact assessment methdology, June 2016, Thailand, organized by ESCAP together with UNDP and RIMES;
b) Regional training on multi-hazard early warning systems, September 2016, Hyderabad, India, organized by ESCAP, jointly with INCOIS and RSMC, New Delhi; and
c) Regional training workshop on flood forecasting and early warning in transboundary river basins, October 2016, Thailand, organized by ESCAP, jointly with RIMES.

1.5.3. Bangladesh

The representative of Bangladesh informed that BMD is contributing in the PTC News letter in a regular manner. DEW DROP, a scientific journal of geophysics and meteorology is being published by Bangladesh Meteorological Department once in a year.

1.5.4 India

1.5.4.1 Current Status

Research works pertaining to statistical, climatological and dynamical aspects of Tropical Cyclones of North Indian Ocean are undertaken regularly. Some recent efforts are listed below:

1.5.4.2. TCRAIN Project

A Tropical Cyclone Rainfall Analytical tool for the North Indian Ocean – **TCRAIN** that depicts rainfall characteristics of 59 Tropical Cyclones over North Indian Ocean during the period 2000-2015 was developed based on TRMM data by CWRC, RMC Chennai and the application is hosted in the web at the URL: www.cwrcimdchennaitcrain.in. The necessary software for generation of percentage frequency distribution of rain rates, azimuthally averaged radial profiles of rain rates and quadrant-wise mean rain rates around a cyclone centre and with respect to the direction of movement of the cyclone using 3hrly TRMM data was developed in-house. The products are generated for different stages of intensity of the system viz., (i) Depression, (ii) Cyclonic Storm and (iii) Severe Cyclonic Storm and above during its growth as well as decay for all the **59** cyclones would serve as valuable inputs for research on rainfall associated with Tropical Cyclones of the North Indian Ocean.

1.5.4.3 Research Papers

The following research papers were published:

1. Tropical cyclones and climate change. Walsh, K.J.E., J.L. McBride, P.J. Klotzbach, Balachandran, S.J. Camargo, G. Holland, T.R. Knutson, J. Kossin, T.-C. Lee, A. Sobel, and M. Sugi, 2015:*WIRES Climate Change* 65–89. doi: 10.1002/wcc.371.
2. *TCRAIN – A Database of Tropical Cyclone Raifall Products for North Indian Ocean* S. Balachandran, B. Geetha, K. Ramesh, N. Selvam , *Tropical Cyclone Research and Review. 2014, 3 (**2**): 122*; **doi:** 10.6057/2014TCRR02.05
3. Eddy Angular Momentum Fluxes in Relation with Intensity Changes of Tropical Cyclones Jal (2010) and Thane (2011) in North Indian Ocean . Balachandaran S. and Geetha B. (2013), 'High Impact Weather Events over the SAARC Region' , pp164-176, Capital Publishing Company, New Delhi
4. M Mohapatra & Monica Sharma, "Characteristics of surface wind structure of tropical cyclones over the north Indian Ocean" Journal of Earth System Science, 124(7):1573- 1598. DOI:10.1007/s12040-015-0613-6, Impact Factor 1.04.
5. M Mohapatra, "Tropical cyclone forecast verification by India Meteorological Department For north Indian Ocean: a review", Tropical Cyclone Research and Review, 03, 1-14.
6. M Mohapatra, B. Geetha, S. Balachandran and L.S. Rathore, " On the Tropical Cyclone Activity and Associated Environmental Features over North Indian Ocean

in the Context of Climate Change, Journal of Climate Change", Journal of Climate Change,1, 1-26.

7. M Mohapatra, B. Geetha, S. Balachandran and L.S. Rathore, "On the Tropical cyclone activity and associated environmental features over North Indian Ocean in the Context of Climate change" Journal of Climate Change, Vol.1 No. 1-2 (2015), pp-1-26, DOI : 10.3233/ JCC-150001.
8. M Mohapatra, D P Nayak, Monica Sharma, R P Sharma & B K Bandyopadhyay, "Evaluation of official tropical cyclone landfall forecast issued by India Meteorological Department" Journal of Earth System Science, 124(4), 861-874, DOI:10.1007/s12040- 015-0581-x, Impact Factor 1.04
9. S. D. Kotal, Sumit Kumar Bhattacharya, S. K. Roy Bhowmik And P. K. Kundu, Verification of forecasts of IMD NWP based cyclone prediction system (CPS) for cyclones over the north Indian seas during 2013, MAUSAM, 66, 3 (July 2015), 497-510, 551.509.5 : 551.509.313.6 : 551.515.2 (267)
10. Y. V. Rama Rao, K. Nagaratna, D. Joardar, Arun Sharma And Anil Kumar, "Evaluation of short range forecast for tropical cyclones over north Indian Ocean using TIGGE data", MAUSAM, 66, 3 (July 2015), 529-540, 551.509.5 : 551.515.2 (267)
11. G. P. Singh, Medha Khole and D. M. Rase, "Extreme rainfall events and urban floods in the growing cities of India, MAUSAM, 66, 3 (Oct 2015), 825-840, 551.557(540).
12. S. Nath, S. D. Kotal, P. K. Kundu, "Seasonal prediction of tropical cyclone activity over the North Indian Ocean using the neural network model", Atmósfera 28(4), 2015, 271-281.

1.5.4.4. Participation in Seminar / Symposium / Conference

1. Dr.S.Balachandran, Scientist-E, participated in International Training Workshop of seven countries, on Tropical Cyclone Forecasting (ITWTCF-2015) during 3-14, August, 2015 at New Delhi and elivered talk on North Indian Ocean Tropical cyclone – Climatology and variability.
2. A meeting on development of standard operation procedure for Dam safety during cyclone period was held at IMD, New Delhi with experts from Cyclone Warning Division, Hydrometeorology Division of IMD and Central Water Commission on 20th January, 2016
3. Dr.M.Mohapatra, Sc.G (Services) participated in the 1st meeting of Indo-Russia joint commission for cooperation in the field of Disaster management on 22nd March 2016 at New Delhi and presented the Early warning system of IMD.
4. Dr. M. Mohapatra, Scientist 'E', participated in a conference on Disaster Risk Reduction held by Govt. of Bihar at Patna during 13-14 May, 2015. He chaired the Panel Discussion of the Technical Session on Effective Multihazards Early Warning Systems and Hazard Monitoring.
5. Dr. M. Mohapatra, delivered a lecture on 8 May, 2015 on "Tropical Cyclone Genesis, impact and future scenario associated with climate change" in a training programme on 'Geo-Spatial Technologies for Coastal and Marine Disaster Management and Climate Change", conducted by Indian Institute of Remote Sensing, Dehradun and UN-ESCAP, Bangkok at Dehradun.

6. Dr. S. C. Sahu, Scientist 'F', delivered lecture on "Disaster Need Assessment: Weather Forecasting, Warning and Dissemination System for Preparedness, Evacuation and other Measures" and Climate change adaptation and disaster need assessment" at The Gopabandhu Academy of th Administration on 7 September, 2015.
7. Dr. S. Balachandran, Scientist 'E' participated in WMO Eighth Tropical cyclone RSMCs/TCWCs Technical Coordination Meeting (TCM-08) at Miami, Florida, USA during 2 to 6 November, 2015. He made presentation on recent activities and future plans of RSMC, New Delhi.

1.5.4.5. Other Publications

- Annual RSMC Report on Cyclonic Disturbances
- Annual Tropical Cyclone Operation Plan (TCP-21)
- WMO/ESCAP Panel News
- Annual Report of Cyclone Warning Division, IMD and Ministry of Earth Sciences (MoES), Government of India
- News Letters : IMD and MoES
- Preliminary reports of cyclonic disturbances
- A book entitled, 'Tropical Cyclone Activity over the North Indian Ocean' edited by Dr. M Mohapatra, Mr. BK Bandyopadhya and Dr. LS Rathore was co-published by Capital publishers, New Delhi and Springers

1.5.4.6. Ongoing Projects

- A project on development and execution of a software tool **TCWIND** - for depicting winds associated with 43 Tropical Cyclones over North Indian Ocean during 2000-2010 (time series of maximum sustained wind speed, vertical wind shear, tangential and radial velocities) based on IMD's best track data and 6-hrly NCEP FNL data is in progress.
- **Statistical prediction of seasonal cyclonic activity over the North Indian Ocean**
  An experimental outlook on the seasonal cyclonic activity over the North Indian Ocean for the period October-December 2014 and 2015 was prepared on real-time basis (during September 2014 and 2015 respectively) based on two different statistical models. The prediction was validated at the end of the season. Efforts are on for improving the prediction models.

1.5.5. Pakistan

The representative of Pakistan informed the Panel that Pakistan Meteorological Department (PMD) is also committed to promote research activities in the field of meteorology, hydrology, climate change, geophysics and other related disciplines for improving meteorological services for the benefit of the people. As part of its efforts, PMD started publication of its biennial research journal namely "Pakistan Journal of Meteorology" in 2004. During 2015, PMD published two issues (No. 22 and 23) of "Pakistan Journal of Meteorology". These issues contain 13 research papers which were contributed by the scientists of PMD in addition to foreign researchers. Scientists of PMD also contributed (both as lead authors and co authors) in around ten (10) research papers which have been published in various national and international journals like Climate Dynamics, Journal of Glaciology, Journal of Earth Science & Climatic Change and /or presented at international scientific conferences and have been published in the proceedings of these conferences/ seminar.

1.5.5.1 Development of Future climate scenarios:

The Research & Development Division of PMD has developed high resolution climate change scenarios for Pakistan by downscaling General Circulation Models (GCMs) use in IPCC AR5. The climate scenarios are at 25km and 50km grid resolution on the basis of Representative Concentration Pathways (RCP); RCP 4.5 and RCP 8.5 emission scenarios. The future projections data (climate) is discriminated to different research institutes, government and non-governmental agencies in the form of DVD for further research in the field of climate disaster mitigation and adaptation. The same data is also available on PMD website with open access.

1.5.5.2. National Agrometeorological Centre (NMAC) of PMD regularly publishes monthly agrometerological bulletins for the facilitation of farming community. NAMC aslo publish crops reports and other technical reports and keeps close liaison with Agriculture Universities and research centers. National Drought Monitoring Centre is another unit of PMD which regulary issues fortnightly drought bulletin regarding drought situation in the country.

1.5.6. Sri Lanka

The representative of Sri Lanka informed the Panel that the following research studies were conducted by the Department during the year 2015

1. Modulation of Seasonal Rainfall in Sri Lanka by ENSO Extremes
2. Identification of Suitable predictors to Develop a Seasonal Forecasting Model for District Rainfall for the onset of Maha Agricultural Season using Climate Predictability Tool (CPT)
3. Analysis of Standard Precipitation Indices to Identify for Drought Condition in 2015
4. Simulate Heavy Rainfall During 19th to 28th December 2014 Using WRF for Different Atmospheric Physics
5. The Influence of La Nina on Sri Lanka Rainfall
6. Synoptic Analysis of Catastrophe Heavy Rain and Strong winds over Sri Lanka on 01st June 2014
7. Influence of Large-scale circulation features and El Nino conditions on Southwest Monsoon Rainfall 2015 in Sri Lanka

   A comparative study on cloud radiative forcing over Sri Lanka and Indian monsoon region

1.6. Publications

1.6.1.Panel News

Panel News letter of PTC is a bi-annual document which is issued after every six months. During 2015-2016 two (02) publications of PTC newsletter "Panel News" Issue No. 39, 40

were published and the same were distributed among PTC Members, WMO, ESCAP and other concerned.
The PTC Secretariat requested the Panel Member countries to carefully review the current Panel News issues, and send their views/comments to PTC Secretariat for further improving the quality of the Panel News.
PTC Secretariat requested the respected Panel Members to provide their contributions in the form of news material related to development activities, science news, training workshops, research reports etc. in their respective countries to PTC Secretariat through their Panel News Correspondents so that next issues of the Panel News can be published timely.
PTC Secretariat requested Panel Members to send their contribution by 31 May 2016 for 41st Edition.
Panel agreed to stop providing hard copy of PTC Newsletters in order to minimize expenses and instead sending of e-version of the Newsletters by email and to upload same on the PTC website.

1.6.2. Annual Cyclone Review-2014
Dr, M Mohapatra, Head, RSMC, New Delhi informed that Annual Cyclone Review has been completed and been sent to WMO for publication

1.6.3. Annual Report on cyclonic distrurbances over north Indian Ocean
Dr, M Mohapatra, Head, RSMC, New Delhi informed that Annual Report on cyclonic disturbances over the North Indian Ocean during 2015 has been completed and been published. The same is also available in RSMC, New Delhi website.

1.7. REVIEW OF THE TROPICAL CYCLONE OPERATIONAL PLAN

1.7.1 The Panel appreciated Dr. M. Mohapatra of RSMC New Delhi for his valuable services extended in updating the Operational Plan of the PTC. List of Important Addresses and Telephone Numbers Connected with Tropical Cyclone Warning in the Panel Countries (ANNEX V-A-1 of the WMO/Tropical Cyclone Programme Report No. TCP-21, edition 2015) which was re-established by Dr. Mohapatra, rapporteur of Tropical Cyclone Operational Plan (TCOP) in 2015, with the support of the PTC Secretariat and in response to the recommendation of the Panel made at the 41st Session in Bangladesh and 42nd session in Thailand.

1.7.2 The PTC Secretariat requested the Panel Members to make a careful review of TCOP available at www.rsmcnewdelhi.imd.gov.in and inform to the RSMC New Delhi and PTC Secretariat about the updates/additions/amendments, if any, before middle of June 2016. Panel requested Dr M Mohapatra to act as Rapporteur for the year 2016 to update the Operational Plan of PTC.

1.8. Coordinated Technical Plan (2016-19) and Annual Operational Plan (2016)

The detailed coordinated technical plan and annual operational plan was discussed and apapted in the session. The same are presented in **Chapter IV** and **V** respectively

1.9. PTC SECRETARIAT

1.9.1 Secretary of PTC conveyed thanks to the Panel on the confidence that Panel reposed on him and Pakistan with regards to the hosting of the PTC Secretariat.

1.9.2 On behalf of PTC secretariat, Mr. Alf Shareef, Vice-Chair of the PTC briefed the Panel on the activities of PTC Secretariat during the inter-sessional period. The Panel expressed its satisfaction with the work of the PTC Secretariat. The summary of the activities of PTC Secretariat is given in **CHAPTER VI**

1.9.3 The PTC Secretariat provided the Panel with a detailed breakdown of its expenses incurred during the Inter-sessional period (**Appendix I**). Upon request of the PTC Secretariat, the Panel agreed to provide US$ 4,000 to support the activities of the PTC Secretariat 2016.

1.10 SUPPORT FOR THE PANEL'S PROGRAMME

1.10.1. PTC Trust Fund

1.10.1.1. The Panel agreed to the participation of Secretary of PTC in the 49th Session of ESCAP/WMO Typhoon Committee as well as in the Annual Session of UN-ESCAP through PTC Trust Fund.

1.10.1.2. The Panel reaffirmed that the Panel on Tropical Cyclones Trust Fund (PTCTF) should be used for achieving self-reliance of the Panel and thus be used not only for the provision of institutional support but also as funding support to the representatives of the Panel Members attending training events and conferences.

1.10.1.3. The Panel endorsed the use of the Trust fund for 2016 for the following specific purpose:

1. Support to the attachment training at RSMC, New Delhi for per diem of the participants (US$ 6,000)
2. Support to the attachment training on storm surge in India for per diem of the participants (US$4,000)
3. Support to the PTC Secretariat for its operating expenses and running of the PTC-website (US$ 4,000)
4. Support to the participation of Secretary of PTC in the 11th Session of ICG/IOTWS

1.10.1.4. A detailed financial report of the Trust Fund as of 31 December 2015 was submitted by WMO to the Panel (**Appendix-II**).

1.10.2. Resources and Support

A document provided by the WMO Development and Regional Activities Department (WMO/DRA) has been presented to the Panel and is given in **Appendix-III**.

1.10.3. Review of the Terms of Reference (ToRs) of the Working Groups and Secretariat of the Panel

The ToRs of the WGs and the PTC Secretariat were presented by the Vice-Chair of PTC and were endorsed by the Panel members as given in **Appendix-IV and V**.

1.10.3.1. Reports of Working Groups

1.10.3.1.1. Working Group on Hydrology (WGH)

URBAN FLOOD RISK MANAGEMENT

The PTC member countries are facing multiple flood hazards such as Heavy rains due to cyclones which cause urban floods and inundate the whole city. Summer monsoon inherently provides torrential rains due to the moist current, monsoon low or depression each year .It generates urban floods causing inundation. Some cities in south east Asia are locating in the vicinity of major subduction fault line in the Sea ,which can trigger Tsunomogenic earthquake and inundation of the city.Some of the highly populated cities of the member countries are have such topography in which these are located near a flood plains and are affected by river floods as well as by urban floods due to heavy rains over the city and on the watersheds of the rivers passing through or near the city .While some cities are near to the coasts which fight against not only the storm surge but also the inundation due to the River floods ,where as in some cases it is at three pronged attack when the city falls in the grip of inundation due to tsunami ,storm surge and overhead heavy rains.

Consequently high financial losses occur to public exchequer in terms of destruction of infrastructure, loss of Human lives and Environmental degradation .Therefore it is the urgent need to develop an urban flood and risk management project to minimize the loses and damages.

Basically the Urban floods occur due to the following factors

- Torrential rain
- Less capacity of drainage system with respect to rain intensity
- Irregular topography
- Environmental pollution

To effectively mitigating urban floods and efficient Early warning is required which should be capable enough to make short, medium and long rang quantitative rain forecast.The prerequisite for such system the following studies are essential to be conducted for finding the root causes to propose suitable solution for managing the urban flood. This information’s will also provide the scale of the flood for designing appropriate contingency plan and baseline for the remedial actions.

1: Probable Maximum precipitation,
2: Probable Maximum Flood
4: Inundation mapping for flood through rain and Tsunami (if required)
5: Disaster risk analysis and risk factor,
6: Storm rating, mass and frequency curve
7: Standing operating procedure.

1.10.3.1.2. Rainfall / Cyclone monitoring & flood forecasting for mega cities

Dr. M. Mohapatra in his presentation on Rainfall / Cyclone monitoring & flood forecasting for mega cities (www.rsmcnewdelhi.imd.gov.in) discussed that for an effective flood forecast and flood management, the information on the city's Hydro-Meteorological Parameters such as water bodies and their water level, drainage system, soil moisture, run off, and the city specific critical thresholds of rainfall for warning purpose is required. Also the hydrological model outputs are required for the decision support system. With this information Impact based warning products generation in text and graphics in GIS platform and suggested actions can be generated. For better generation and understanding of the forecast, there is need for capacity building of forecasters and stakeholders through regular training.

1.10.3.1.3. ACTIVITIES BY ESCAP

The Panel recognizes the urgent need to address urban flood risk. In this regard, the Panel recommends ESCAP and WMO to organize a joint expert meeting of the WMO/ESCAP Panel on Tropical Cyclones and the ESCAP/WMO Typhoon Committee to share experiences and expertise in managing urban flood risk in 2017. A project proposal on urban flood risk management of the Panel on Tropical Cyclones may be developed based on the discussions and information from the meeting.

1.10.3.2. Working Group on Disaster Risk Reduction (WGDRR)

1.10.3.2.1. ACTIVITIES OF THE ESCAP

1.10.3.2.1.1. Implementation of SFDRR in Asia-Pacific: International Network for Multi-Hazard Early Warning Systems (NM-HEWS)

The *Sendai Framework for Disaster Risk Reduction 2015-2030* (the Sendai Framework) calls for enhancing and strengthening multi-hazard early warning systems (MHEWS). In response to this call, the International Network for MHEWS (IN-MHEWS) was established as a multi-stakeholder partnership that will facilitate the sharing of expertise and good practices for MHEWS. Member States of ESCAP also recognized the need to strengthen people-centred multi-hazard early warning systems and requested the ESCAP secretariat to work on multi-hazard early warning systems at the regional level by deepening and extending regional coordination mechanisms for multi-hazard early warning systems including the WMO/ESCAP Panel on Tropical Cyclones and the ESCAP/WMO Typhoon Committee. In this regard, ESCAP will work with the Panel in strengthening the work of the Panel on multi-hazard early warning systems. For details, kindly see **Appendix VI.**

1.10.3.2.1.2. Impact-based Forecasting

Decision-makers and the public often found difficult to understand forecasting products and early warning in technical terms. Impact-based forecasting involves translation of hazard information into the potential impact as well as associated sectoral damage and loss under different scenarios. It enables engagement of all the key stakeholders for better disaster preparedness. ESCAP and UNDP, in collaboration with RIMES, is currently developing methodological options for impact-based forecasting. ESCAP will also work with the Panel on Tropical Cyclones to promote and build the capacity for the impact-based forecasting in the region.

1.11. SCIENTIFIC LECTURES

1.11.1 Presentations of scientific lectures

Following scientific lectures were delivered during this session.

1. *Flood monitoring and forecasting in India:* by Director, Central Water Commission, Govt. of India
2. *Disaster Risk Reduction Initiatives in India*: by Prof Santosh Kumar

3. *Storm Surge and Coastal Inundation Modeling*: by Prof. A.D. Rao
4. *Wave Monitoring and Forecasting In India*: By Dr T. BalaKrishnan
5. *Tropical cyclone advisory information for international civil aviation*, by Mr. Peter Dunda of ICAO
6. *On impact based forecasting - the experience of 2015/2016 El Nino,* by Dr. Sanjay Srivastava, Chief of Disaster Risk Reduction Section of ESCAP
7. *RIMES services to PTC*: by Dr. A.R. Subbiah, Director of RIMES

These lectures can be downloaded from the link http://rsmcnewdelhi.imd.gov.in

The Members thanked all the Resource Persons for delivering the scientific lectures, which helped in sharing of knowledge and experience.

1.11.2. Summary of lectures

Lecture Nr 5 : Considering the significant impact of tropical cyclones on the safety, regularity and efficiency of the air traffic system, and in view of air transportation's major role in global economic and social development – and the continuing, significant growth of air traffic – actions that lead to improved availability and quality of information on the occurrence or expected occurrence of tropical cyclones in support of international civil aviation operations can be viewed as positively contributing to the overall objectives of the PTC.

ICAO, in close coordination with WMO, develops the policies and Standards for meteorological service for international air navigation (contained in Annex 3 to the Convention on Civil Aviation) deemed necessary or desirable for safe and regular international air navigation. Annex 3 requires the provision of tropical cyclone advisory information by designated tropical cyclone advisory centres (TCACs).

Tropical cyclone advisory information provided by the TCACs should be provided in graphical format in addition to the required alphanumeric format. Information on tropical cyclones is also contained in the significant weather (SIGWX) forecasts issued by the two world area forecast centres (WAFCs). As a means of harmonizing the information on tropical cyclones, the TCACs are invited to participate in routine coordination sessions hosted by WAFC Washington.

The 2013 fourth edition of ICAO's Global Air Navigation Plan (GANP) (Doc 9750) introduces a rolling fifteen-year strategy for air transport improvements to 2028 and beyond — that will eventually realize a fully-harmonized global air navigation system. Meteorological information will be a key enabler to the realization of the global air traffic management operational concept envisioned by the GANP; future developments in aeronautical meteorological service will support improvements in global interoperability of systems and data.

Interoperability within the future air traffic system relies on the concept of system-wide information management (SWIM). The success of SWIM will be, in part, contingent upon the exchange of digital information that uses non-proprietary, open-source code forms such as the extensible markup language (XML) and the geography markup language (GML), since these will allow for the required streamlined sharing of information.

The transition to digital meteorological information exchange that will support the meteorological-component of SWIM commenced with Amendment 76 to Annex 3, applicable in November 2013, which enabled the exchange of aeronautical meteorological messages (specifically METAR, SPECI, TAF and SIGMET) in digital form using XML/GML by States in a position to do so. Amendment 77 to Annex 3, applicable in November 2016, upgrades the initial enabling provisions to the status of *Recommendation* and extends the requirement for digital exchange using XML/GML to other meteorological information including tropical cyclone advisory information.

Guidance on the information exchange model, XML/GML and the metadata profile is provided in the Manual on the Digital Exchange of Aeronautical Meteorological Information (ICAO Doc 10003).

To support implementation of Amendment 77 to Annex 3, States should consider the essential steps, including the development of software modifications, training of operational staff, testing of software and communications infrastructure, and operational acceptance of software changes, which are required in addition to addressing the modified ICAO provisions in national regulations and national implementation plans. Additionally, States may explore opportunities for twinning/mentoring arrangements to assist States in the implementation of digital information exchange.

In view of the above, the meeting recognized the importance of:

- Full implementation of the ICAO provisions related to the content, format and dissemination of tropical cyclone advisory information;
- Coordination of the information on tropical cyclones issued by the TCACs and WAFCs; and
- Migration to the digital exchange of meteorological information to support international air navigation, including tropical cyclone advisory information, and the essential steps to be followed by States in order to implement the proposed Amendment 77 to Annex 3.

1.12 Other issues:

1.12.1 On the suggestion by Sri Lanka, the Panel agreed that RIMES may be requested to support the PTC in capacity building, strengthening observational and forecasting network in the PTC member countries.

1.12.2. Sri Lanka suggested the need for more capacity building activities for tropical cyclone forecasters in the PTC region. The Panel ***requested*** WMO to consider supporting training of tropical cyclone forecasters of PTC in various training activities conducted under the WMO-TCP and WWRP within and outside of the PTC region.

1.12.3. The Panel recognized the urgent need to address urban flood risk. In this regard, the Panel ***recommended*** ESCAP and WMO to organize a joint expert meeting of the WMO/ESCAP Panel on Tropical Cyclones and the ESCAP/WMO Typhoon Committee to share experiences and expertise in managing urban flood risk in 2017. A project proposal on urban flood risk management of the Panel on Tropical Cyclones may be developed based on the discussions and information from the meeting.

1.13. DATE AND PLACE OF THE FORTY-FOURTH SESSION

The Panel noted and appreciated that Maldives offered to host the 44th Session of the PTC in Maldives in 2017 subject to the approval of its Government. Dates will be determined in consultation with WMO, ESCAP and PTC Secretariat.

1.14. ADOPTION OF THE REPORT

The report of the forty-third session was adopted at 13:30 hours on Friday 6th May, 2016.

1.15. CLOSURE OF THE SESSION

The session closed at 13:40 hours on Friday 6th May, 2016.

CHAPTER-II

CYCLONIC ACTIVITIES OVER NORTH INDIAN OCEAN DURING 2015

A. Annual Activity

During the year 2015, 12 cyclonic disturbances developed over north Indian Ocean including two Extremely Severe Cyclonic Storm (ESCS) and one Cyclonic Storm (CS) and two deep deression over Arabian Sea where as one cyclonic storm, one deep deression and one depression over Bay of Bengal.Four land depression (D) also formed during 2015. Considering season-wise distribution, out of 12 disturbances, eight during monsoon and three during post-monsoon season. Salient features of cyclonic disturbances during 2015 are given below.

i. There was one cyclone over the Bay of Bengal and three over the Arabian Sea against the long period average of 5 per year over the entire north Indian Ocean including about four over Bay of Bengal and one over Arabian Sea. Thus the cyclonic activity was subdued in the Bay of Bengal during the year 2015. However, the frequency of very severe cyclonic storms was near normal (two)
ii. Though there were four cyclones, none of thse crossed Indian coast. CS Ashobaa dissipated over Sea, CS Komen crossed Bangladesh coast and Chapala & Megh crossed Yemen coast
iii. Velocity Flux, Accumulated cyclone energy and Power Distribution Index of the period 2015 are 56.25, 33.92 and 26.34 against long period average based on the data of 1990-2013 and 21.17, 13.09 and 9.67 respectively.
iv. The total duration of cyclonic disturbances during 2015 was 44.5 days against the long period average of 29.4 days based on data of 1990-2013.

Details of the cyclonic disturbances formed over the north Indian Ocean and adjoining land areas are given in Table 2.1-2.3. The tracks of these disturbances are shown in Fig. 2.1

Table 2.1 Brief statistics of cyclonic disturbances over NIO and adjoining land areas during 2015:

1.	Cyclonic Storm, ASHOBAA, over Arabian Sea (07-12 June, 2015)
2.	Depression over Bay of Bengal (20-21 June, 2015)
3.	Deep depression over Arabian Sea (22-24 June, 2015)
4.	Land Depression (10-12 July, 2015)
5.	Land Deep Depression (27 - 30 July, 2015)
6.	Cyclonic Storm, KOMEN, over Bay of Bengal (26 Jul – 2 Aug 2015)
7.	Land Depression (4 August, 2015)
8.	Land Deep Depression (16 -19 September, 2015)
9.	Deep depression over Arabian Sea (09-12 October, 2015)
10.	Extremely Severe Cyclonic Storm, CHAPALA, over Arabian Sea (28 October- 04 November 2015)
11.	Extremely Severe Cyclonic Storm, MEGH, over Arabian Sea (05 – 10 November, 2015)
12.	Deep depression over Bay of Bengal (08-10 November, 2015)

Table 2.2 Some Characteristic features of cyclonic disturbances formed over north Indian Ocean and adjoining region during 2015

S. No.	Cyclonic storm/ Depression	Date, Time& Place of genesis (Lat. N/long E)	Date, Time (UTC) Place (Lat./Long .) of Landfall	Estimated lowest central pressure, Time & Date (UTC) & Lat°N/long °E	Estimated Maximum wind speed (kt), Date & Time	Max T. No. Attained
1	Cyclonic Storm (CS) ASHOBAA over the Arabian Sea (07-12 June, 2015)	07th Jun-2015, 0300 UTC over east central Arabian Sea(14.5/68.5).	Weakened into a well-marked low pressure over northwest Arabian Sea and adjoining Oman coast at 1200 UTC on 12th Jun-2015	990 hPa at 0600 UTC on 09th Jun-2015 near (20.3/64.6)	45 knots at 1800 UTC of 09th June, 2015	T 3.0
2	Depression over Bay of Bengal(20-22 June, 2015)	20th Jun-2015, 0300 UTC over northwest and adjoining west central Bay of Bengal (18.0/86.0)	Crossed Odisha coast between Gopalpur and Puri (19.7/85)between 2000-2100 UTC on 20th Jun-2015	990 hPa at 0300 UTC 20th Jun-2015 near (18.0/86.0)	25knots at 0300 UTC of 20th June, 2015	T 1.5
3	Deep Depression over Arabian Sea (22– 25 June, 2015)	22nd Jun-2015, 0300 UTC over northeast and adjoining Arabian Sea(20.0/67.0).	Crossed South Gujarat coast near Diu (21.0/71.3) between 0900 -1000 UTC on 23rd June 2015	988 hPa at 0300 UTC 23rd June, 2015 near (20.5/70.5)	30 knots at 0300 UTC of 23rd June, 2015	T 2.0

4	Land Depression (10-12 July, 2015)	10th Jul, 2015, 0300 UTC over Jharkhand and neighbourhood (23.1/85.1)	Weakened into a well-marked low pressure area over northwest Uttar Pradesh and adjoining Haryana at 1200 UTC on 12th July, 2015	994 hPa at 0900 UTC 10th Jul, 2015 near (23.3/84.0)	25 knots at 0300 UTC 10th Jul, 2015	-
5	Land Deep Depression (27-30 July, 2015)	27th Jul-2015, 1200 UTC over southwest Rajasthan and adjoining Gujarat(26.7/71.8).	Weakened into a well-marked low pressure area over west Rajasthan and neighbor-hood at0300 UTC on 30th July, 2015.	994 hPa at 1200 UTC 27th Jul-2015 near (26.2/71.8)	30knots at 0300 UTC 28th Jul-2015	-
6	Cyclonic Storm, KOMEN Over bay of Bengal(26 July –2 August, 2015)	26th Jul-2015, 0000 UTC over northeast Bay of Bengal and adjoining coastal area of Bangladesh & Gangetic West Bengal(22.0/90.8).	Crossed Bangladesh coast (near lat. 91.4^{0}E) between 1400-1500 UTC of 30th July	986 hPa at 1800 UTC 29th Jul, 2015 near (21.6/91.4)	40 knots at 0600 UTC 30-Jul-2015	T 2.5
7	Land Depression (4-5 August, 2015)	04th Aug-2015, 0300 UTC over East Madhya Pradesh and adjoining Chhattisgarh (22.7/80.5)	Weakened into a well-marked low pressure area over southwest Madhya Pradesh and neighbor-hood at	998 hPa at 0300 UTC 04th Aug, 2015 near (22.7/80.5)	25 knotsat 0300 UTC 04th Aug, 2015	-

			0000 UTC on 5th August, 2015.			
8	Land Deep Depression (16 - 19 September, 2015)	16thSep-2015, 0300 UTC over south Odisha and neighbourhood (19.6/83.5)	Weakened into a well-marked low pressure area over north Madhya Maharashtra and adjoining areas of southwest Madhya Pradesh and Gujarat region at 0300 UTC on 19th September, 2015	996 hPa at 1200 UTC 17thSep, 2015 near (20.5/79.0)	30 knots at 0300 UTC 17thSep, 2015	-
9	Deep depression (DD) over Arabian sea (09-12 October 2015)	09thOct-2015, 0000 UTC over eastcentral Arabian Sea(14.0/70.3)	Weakened into a Well-marked low pressure area over eastcentral Arabian Sea at 0300 UTC on 12th October, 2015	1000 hPa at 0600 UTC 10thOct, 2015 near (15.1/69.4)	30 knots at 1800 UTC 09-Oct-2015	T 2.0
10	Extremely severe cyclonic storm CHAPALA over Arabian sea (28 October to 04 November, 2015)	28thOct-2015, 0300 UTC over west central Arabian Sea (11.5/65.0).	Crossed Yemen coast to the southwest of Riyan (14.1/48.65) between 0100-0200 UTC of 3rd November, 2015	940 hPa at 0900 UTC 30thOct, 2015 near (14.2/60.8)	115 knots at 0900 UTC 30thOct, 2015 near	T 6.0

11	Extremely severe cyclonic storm MEGH over Arabian sea (05-10 November, 2015)	05th Nov., 2015, 0000 UTC over westcentral and adjoining southwest Arabian Sea (14.1/66.0)	Crossed Yemen coast (13.4/46.1) at 0900 UTC of 10th November, 2015	964 hPa at 0600 UTC 08th Nov., 2015 near (12.7/54.9)	95 knots at 0600 UTC 08th Nov., 2015	T 5.0
12	Deep Depression over Bay of Bengal (08-10 November, 2015)	08th Nov., 2015, 0300 UTC over southwest Bay of Bengal(10.7/83.7)	Crossed north Tamil Nadu coast close to Marakanam, north of Puducherry (12.2/80.0) at around 1400 UTC on 9th November, 2015	996 hPa at 0600 UTC 09th Nov., 2015 near (11.7/80.1)	30 knots at 1800 UTC 08th Nov., 2015	T 2.0

Table 2.3 Statistical data relating to cyclonic disturbances over the north Indian Ocean during 2015

A) Monthly frequencies of cyclonic disturbances(C I .≥1.5)

S.N	Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.	D						⇔						
2.	DD						⇔				⇔	⇔	
3.	CS						⇔	⇔					
4.	SCS												
5.	VSCS												
6.	ESCS										⇔	⇔	
7.	Land Dep.							⇔ ⇔	⇔	⇔			

Peak ⇔ intensity of the system

B) Life time of cyclonic disturbances during 2015 at different stages of intensity

S.No.	Type	Life Time in (Days)
1	D	20 days 03 hours
2.	DD	09 days 03 hours
3.	CS	07 days 12 hours
4.	SCS	01 days 03 hours
5.	VSCS	02 days 06 hours
6.	ESCS	04 days 09 hours
7	SuCS	-
	Total Life Time in(Days)	44 days 12 hours

C) Frequency distribution of cyclonic distribution with different intensities based on satellite assessment

CI No.≥	**.≥1.5**	**.≥2.0**	**.≥2.5**	**.≥3.0**	**.≥3.5**	**.≥4.0**	**.≥4.5**	**.≥5.0**	**≥5.5**	**≥6.0**
No of Disturbances	12	9	4	3	2	2	2	2	1	1

D) Basin-wise distribution of cyclonic distribution

Basin	**Number of cyclonic disturbances**
Bay of Bengal	3
Arabian Sea	5
Land depression	4

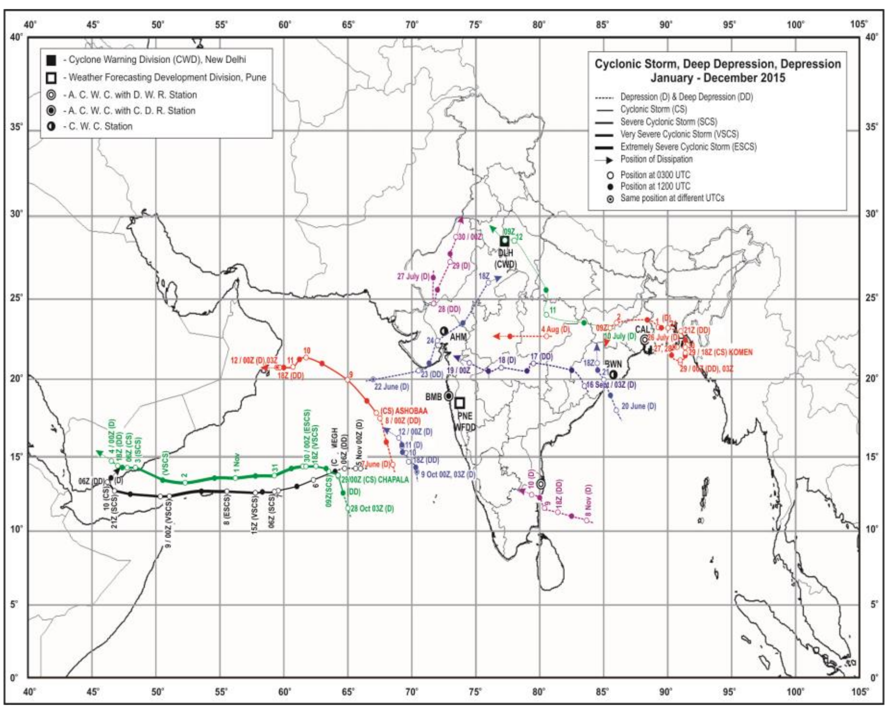


Fig. 2.1 Tracks of the cyclonic disturbances over the north Indian Ocean and adjoining land regions during the year, 2015

B. Description of cyclone during 2015

2.1 Cyclonic Storm, 'ASHOBAA' over the Arabian Sea (07-12 June 2015)

2.1.1 Introduction

The Cyclonic Storm 'ASHOBAA' (07-12 June 2015) developed over eastcentral Arabian Sea from monsoon onset vortex in the morning of 5th June 2015. It gradually moved northwards and became a low pressure area over southeast and adjoining eastcentral Arabian Sea in the morning of 6th June. It concentrated into a Depression (D) in the morning of the 7th June over eastcentral Arabian Sea. Moving nearly north-northwestwards and it intensified into a Deep Depression (DD) in the early hours of 8th June over eastcentral Arabian Sea. It further intensified into the Cyclonic Storm (CS) 'ASHOBAA' in the morning of of 8th June. It gradually intensified till the night of 10th June. Thereafter, while moving west-southwestwards from forenoon of 10th June to morning of 11th June, it encountered high vertical wind shear and low ocean thermal energy and started weakening. It slowly moved westwards over a colder oceanic region and weakened into a deep depression in the night of 11th June. Due to adverse environmental conditions, interaction with land surface and dry air intrusion from western side, it further weakened into a depression in the morning of 12th June and into a well marked low pressure area over northwest Arabian Sea and adjoining Oman coast in the evening of 12th June.

The salient features of this system are as follows.

i. CS 'ASHOBAA' developed over eastcentral Arabian Sea during the onset phase of monsoon.
ii. It had a unique track, as it moved initially northwards, then north-northwestwards and finally west-southwestwards towards Oman coast.
iii. It dissipated over northwest Arabian Sea off Oman coast before landfall.
iv. The NWP and dynamical statistical models provided reasonable guidance with respect to its genesis, track and intensity, though there was large divergence in model guidance with respect to track, intensity and landfall.

Brief life history, characteristic features and associated weather along with performance of numerical weather prediction models and operational forecast of IMD are presented and discussed in following sections.

2.1.2 Monitoring of CS ASHOBAA

The CS 'ASHOBAA' was monitored & predicted continuously since its inception by the IMD. The forecast of its genesis on 7th June, its track, intensity, point & time of landfall were predicted with sufficient lead time.

At the genesis stage, the system was monitored mainly with satellite observations, supported by meteorological buoys and coastal and island observations. Various national and international NWP models and dynamical-statistical models including IMD's and NCMRWF's global and meso-scale models, dynamical statistical models for genesis and intensity were utilized to predict the genesis, track and intensity of the storm. Tropical Cyclone Module, the digitized forecasting system of IMD was utilized for analysis and comparison of various models guidance, decision making process and warning product generation.

2.1.3 Brief life history

2.1.3.1 Genesis

The CS 'ASHOBAA' (07-12 June 2015) developed over eastcentral Arabian Sea from monsoon onset vortex. In association with the southwest monsoon onset over Kerala, a cyclonic circulation in lower levels developed over southeast Arabian Sea on 5th June. It gradually moved northwards and concentrated into a low pressure area over southeast and adjoining eastcentral Arabian Sea on 6th morning. As per satellite imagery, broken low and medium clouds with embedded intense to very intense convection lay over Arabian Sea between latitude 9.0°N & 19.0°N and longitude 61.0°E & 74.0°E in association with the system. The convective clouds remained fragmented in the embedded broad scale cyclonic circulation. The lowest cloud top tempereature was -70°C. The buoy and Ascat observations suggested the associated maximum sustained surface winds of about 10-20 kts. Estimated central pressure was about 1005 hPa. The sea surface temperature was 29-30°C, ocean thermal energy was about 80-100 KJ/cm^2, low level convergence was (10-15)$x10^{-5}$ s^{-1}, upper level divergence was about (10-20)$x10^{-5}$ s^{-1}, the low level relative vorticity was about (5-10)$x10^{-5}$ s^{-1}, vertcal wind shear was low to moderate(10-20 knots). Upper tropospheric ridge lay along 20°N and middle tropospheric ridge was near about 16°N. There was trough in westerlies in middle troposphere to the west of the system. Under these conditions, the low pressure area moved slowly northwards/north-northwestwards and concentrated into a depression over eastcentral Arabian Sea and lay centred at 0300 UTC of 7th June near 14.5^0N/68.5^0E about 700 km southwest of Mumbai. The intensity of the system as per the Dvorak's technique was T1.5. Intense to very intense convection lay over the area between 6.0^0N & 19.5^0N and longitude 63.0^0E & 74.0^0E. Lowest CTT was -70^0C.

2.1.3.2 Intensification and Movement

On 7th June, as the depression lay over eastcentral Arabian Sea, it experienced the ocean thermal energy of about 100-120 KJ/cm^2 with SST of $30\text{-}32^0$C. Compared to previous day, the low level convergence, upper level divergence and low level relative vorticity increased and were about 15-20x $10^{-5}s^{-1}$, 20-30 x $10^{-5}s^{-1}$ and 10-20 x $10^{-5}s^{-1}$ respectively. The vertical wind shear was moderate (10-20 kts). The Madden Julian lay over Phase-2 with amplitude>1. All these environmental and large scale features were favourable for the intensification of the system. The upper tropospheric ridge at 200 hPa level ran along 20^0N. However, there was a trough in westerlies in the middle troposphere to the west of the system. As a result, though the system was far south of upper tropospheric ridge (5.5^0), its westward component was restricted and the system moved nearly north-northwestwards and intensified into a deep depression at 0000 UTC of 8th June over eastcentral Arabian Sea near 17.5^0N/67.5^0E about 600 km west-southwest of Mumbai. It further intensified into the cyclonic storm (CS) 'ASHOBAA' at 0300 UTC of 8th June near 17.9^0N/67.2^0E. As per Dvorak's technique, the intensity was T2.5 and maximum sustained wind (MSW) was 35 Kts. It continued to move north-northwestwards till 0900 UTC of 8th June and then moved northwestwards till 0600 UTC of 9th June. Thereafter, it moved west-northwestwards till 0600 UTC of 10th June and then west-southwestwards till 0000 UTC of 11th June. Finally, it moved westwards on 11th and 12th June. The maximum intensity of T3.0 (45Kts) was maintained till 2100 UTC of 10th June. From the night of 10th June, the lower level convergence, divergence and relative vorticity decreased slightly. The vertical wind shear was moderate near the system centre and was high to the south. As the system moved west-southwestwards from 0600 UTC of 10th June to 0000 UTC of 11th June, it encountered the high vertical wind shear. Further, the ocean thermal energy was less than 50 KJ/cm^2 near the system centre. As a result the intensity of CS'ASHOBAA' decreased from T3.0 (45Kts) at 2100 UTC of 10th June to T2.5 (35Kts) at 0600 UTC of 11th June. On 11th June, as the system moved very slowly westwards over a colder oceanic region, alongwith the adverse environmental conditions like moderate to high vertical wind shear, interaction with land surface and dry air intrusion from western side, it further weakened into a deep depression at 1800 UTC of 11th June near 20.8^0N/59.7^0E. It further weakened into a depression at 0000UTC of 12th June near 20.8^0N/59.5^0E and into a well marked low pressure area over northwest Arabian Sea and adjoining Oman coast at 1200 UTC of 12th June. The system moved west-northwestwards on 9th June as the trough in the middle latitude westerlies moved away eastwards. During 10th to 12th June, the upper tropospheric ridge at 200 hPa level ran along $22\text{-}24^0$ N with an anticyclone located to the northeast of the system centre and another to the northwest. While the anticyclonic circulation in the northeast influenced the system to move northwestwards, the anticyclonic circulation in the northwest tried to restrict movement towards north and rather pushed the system towards southwest. As a result, the system moved slowly westwards during 10-12th June. The observed track of the system is shown in Fig.2.1. The best track parameters of the systems are presented in Table 2.1.1.

Table 2.1.1.Best track positions and other parameters of the Cyclonic Storm, 'ASHOBAA' over the Arabian Sea during 07-12 June, 2015

Date	Time (UTC)	Centre lat.^{0} N/ long. ^{0} E	C.I. NO.	Estimated Central Pressure (hPa)	Estimated Maximum Sustained Surface Wind (kt)	Estimated Pressure drop at the Centre (hPa)	Grade
07/06/2015	0300	14.5/68.5	1.5	1004	25	3	D
	0600	15.0/68.2	1.5	1004	25	3	D
	1200	16.0/68.0	1.5	1003	25	4	D
	1800	16.5/68.0	1.5	1003	25	4	D
08/06/2015	0000	17.5/67.5	2.0	996	30	5	DD
	0300	17.9/67.2	2.5	994	35	7	CS
	0600	17.9/67.2	2.5	994	35	7	CS
	0900	18.5/66.7	2.5	994	35	7	CS
	1200	18.6/66.5	2.5	994	35	7	CS
	1500	18.8/66.2	2.5	994	35	7	CS
	1800	19.2/65.7	2.5	994	35	7	CS
	2100	19.5/65.3	2.5	994	35	7	CS
09/06/2015	0000	20.0/65.0	2.5	992	35	8	CS
	0300	20.0/65.0	2.5	992	35	8	CS
	0600	20.3/64.6	2.5	990	35	10	CS
	0900	20.5/63.8	3.0	990	40	10	CS

	1200	21.0/63.0	3.0	990	40	10	CS
	1500	21.2/62.5	3.0	990	40	10	CS
	1800	21.2/62.5	3.0	990	45	10	CS
	2100	21.3/62.3	3.0	990	45	10	CS
10/06/2015	0000	21.3/62.1	3.0	990	45	10	CS
	0300	21.3/61.8	3.0	990	45	10	CS
	0600	21.3/61.5	3.0	990	45	10	CS
	0900	21.2/61.1	3.0	990	45	10	CS
	1200	21.2/61.1	3.0	990	45	10	CS
	1500	20.9/60.8	3.0	990	45	10	CS
	1800	20.9/60.8	3.0	992	45	10	CS
	2100	20.9/60.8	3.0	992	45	10	CS
11/06/2015	0000	20.8/60.8	2.5	994	40	10	CS
	0300	20.8/60.8	2.5	994	40	10	CS
	0600	20.8/60.5	2.5	994	35	10	CS
	0900	20.8/60.3	2.5	994	35	10	CS
	1200	20.8/60.0	2.5	994	35	10	CS
	1500	20.8/59.7	2.5	994	35	10	CS
	1800	20.8/59.7	2.0	996	30	6	DD
12/06/2015	0000	20.8/59.5	1.5	996	25	4	D
	0300	20.8/59.5	1.5	996	25	4	D
	0600	20.8/59.5	1.5	996	25	4	D
	1200	Well marked low over northwest Arabian Sea and adjoining Oman coast					

2.1.4 Features observed through satellite

Satellite monitoring of the cyclone was mainly done by using half hourly Kalpana-1, INSAT-3D imageries. Satellite imageries of international geostationary satellites Meteosat-7 and MTSAT and microwave & high resolution images of polar orbiting satellites DMSP, NOAA series, TRMM, Metops were also considered. Typical satellite INSAT-3D imageries of CS ASHOBAA representing the life cycle of the cyclone are shown in Fig. 2.1.1(a&b).IMD-GFS analysis of mean sea level (MSLP) and wind at 10m, 850 hPa, 500 hPa & 200 hPa levels are shown in Fig. 2.1.2 (a-f)

Intensity estimation using Dvorak's technique suggested that the system attained an intensity of T 1.5 on 07th June 2015 / 0300 UTC. Associated broken low and medium clouds embedded with intense to very intense convection was seen over the area between 6.0^{0} N & 19.5^{0} N latitudes and 63.0^{0} E & 74.0^{0} E longitudes and convection was seen over 13-21^{0}N and 61-69^{0}E. The lowest CTT was about -93^{0} C. On 9th / 0900 UTC, the system intensified to T 3.0. It showed curved band pattern and covered Lakshadweep. The lowest CTT was about -70^{0}C. At 1200 UTC of 7th, the system intensity was T1.5 and associated broken low and medium clouds embedded with intense to very intense convection was seen over the area between latitude 6.0^{0} N & 21.5^{0} N, longitude 60.0^{0} E & 74.0^{0} E, coastal Karnataka, extreme north Kerala and Lakshadweep. The lowest CTT was about -90^{0} C. At 0000 UTC of 8th, the system attained intensity of T2.0 corresponding to deep depression and at 0300 UTC of 08th, the intensity was T 2.5 corresponding to cyclonic storm. Intense to very intense 0.6 of 10 degree log spiral. Intense to very intense convection was seen over 17.0-22.0^{0} N and to the west of 66.0^0 E. The system continued to show curved band pattern until 10th /0000 UTC and the lowest CTT was about -92^0 C. At 1200 UTC of 10th, the system maintained the intensity of T 3.0 and convection showed central dense overcast pattern. However, a slight decrease in the compactness of the system was observed at 1800 UTC of 10th, convection showed sign of disorganisation and the lowest CTT was -73^0 C. On 11th / 0000 UTC, the intensity of the system decreased to T 2.5. Convection was disorganised and the major convective clouds were observed in the southern sector. Areas of intense convection were over 18.5-22^0 N and to the west of 62.5^0 E. At 0600 UTC of 11th, the major convective clouds were observed in the southern sector was elongated from northeast to southwest direction. At 1800 UTC of 11th, the intensity of the system further decreased to T 2.0. Areas of intense to very intense convection were between 18-24^0 N and to the west of 62.5^0 E and Oman.

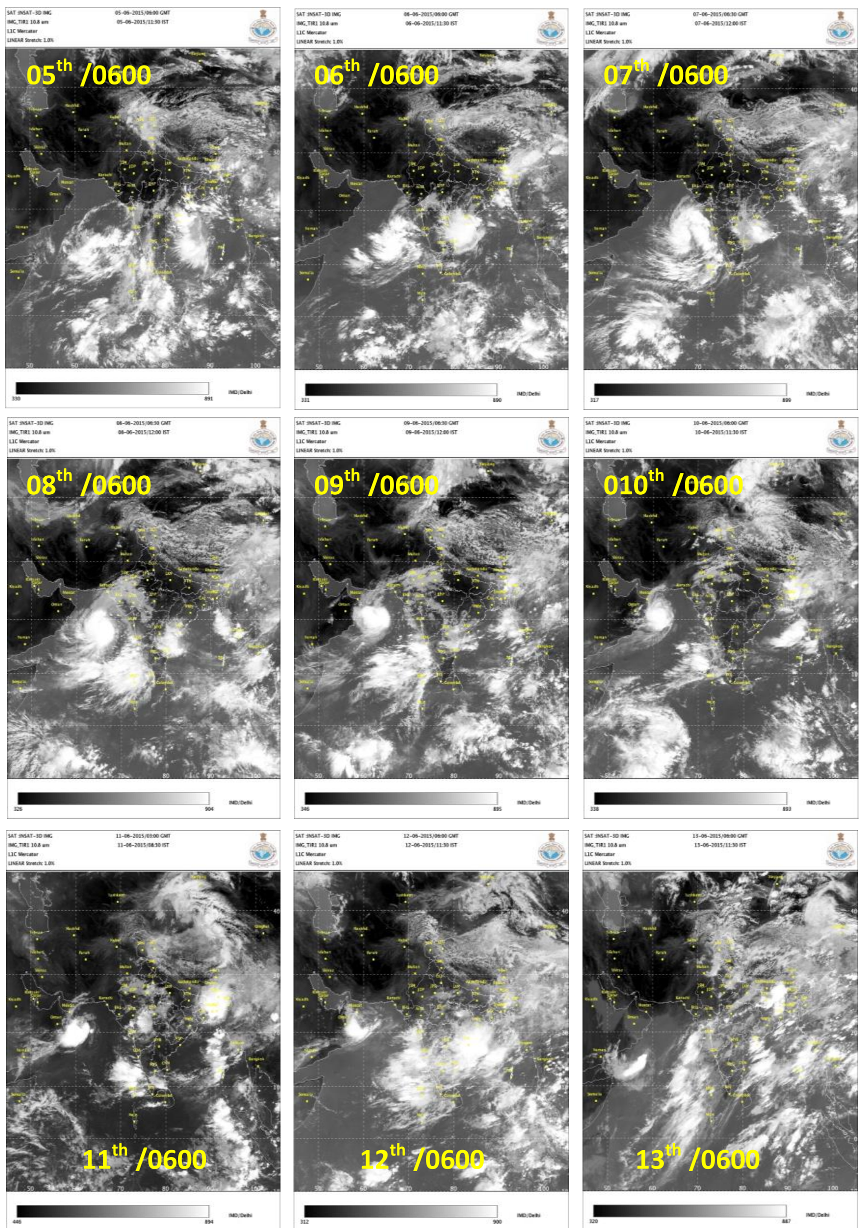


Fig.2.1.1(a) INSAT-3D IR imageries based on 0600

The lowest CTT was -64^0 C. On 12th / 0000 UTC, the intensity of the system became T 1.5. Convection was disorganised with convective clouds sheared to the southwest of the system centre. Moderate to intense convection was seen over 18-23.5^0 N and the west of 61.5^0 E and Oman. Enhanced IR imageries depicting the growth of the system to T 1.5, T 2.0, T 2.5, T 3.0 and its weakening to T 2.5, T 2.0 and T 1.5 are presented in Fig.3. The system further weakened with intensity becoming T1.0 at 1200 UTC of 12th June 2015 corresponding to a well marked low pressure area. It moved over Oman on 13th June as a low level cyclonic circulation.

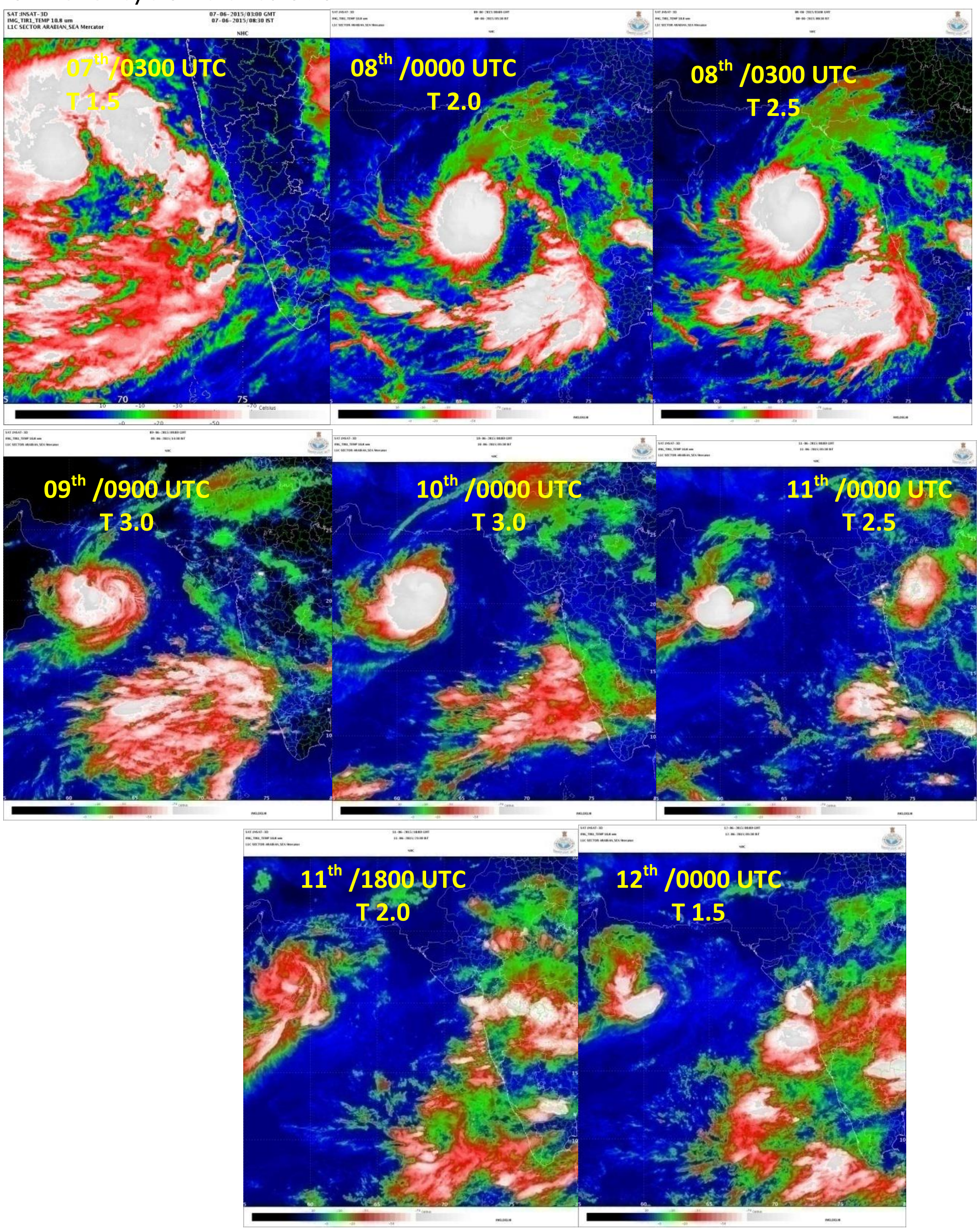


Fig.2.1.1 (b) INSAT-3D IR imageries based on 07/0300, 08/0000, 08/0300, 09/0900, 10/0000, 11/0000, 11/1800 and 12/0000 UTC of June 2015

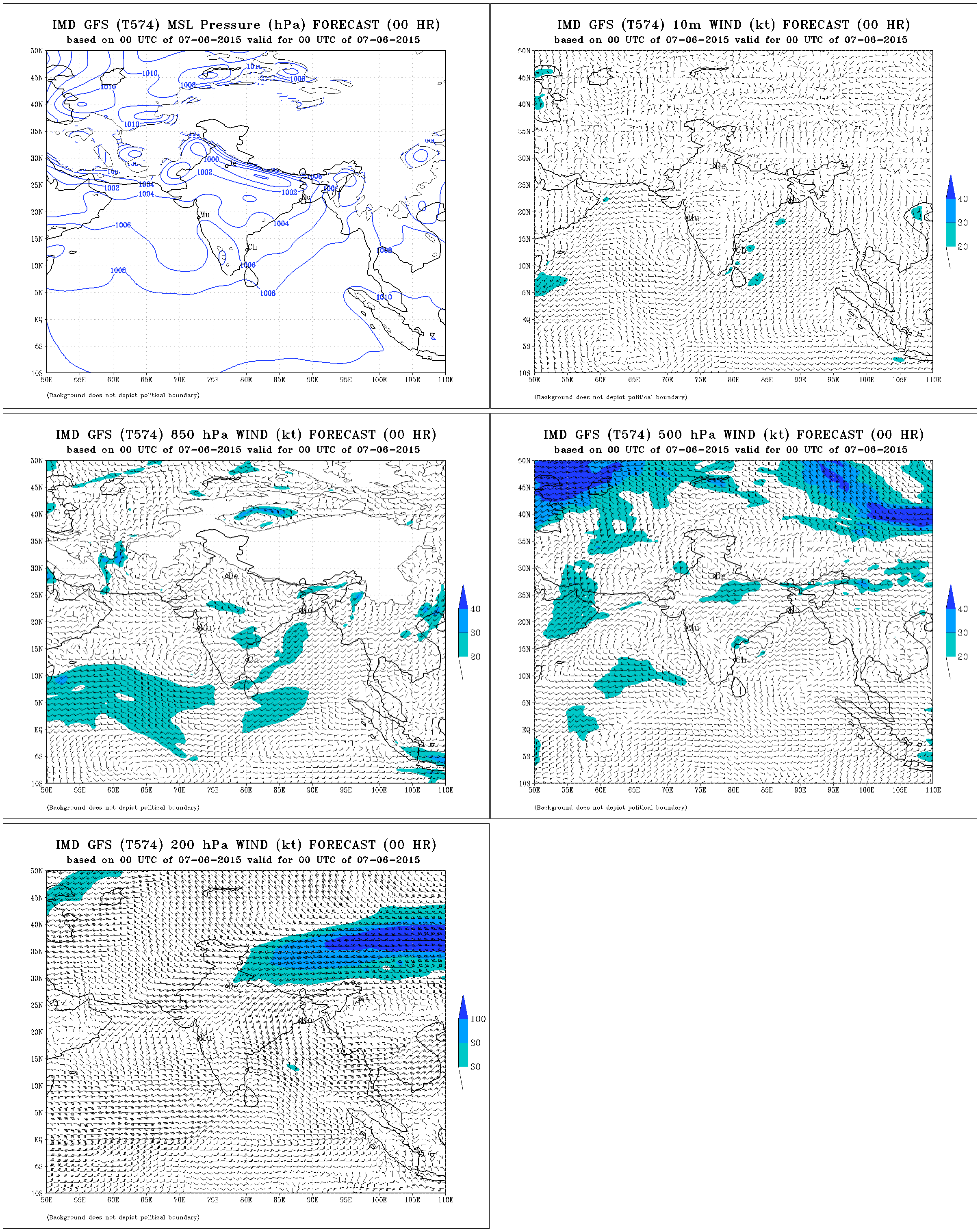


Fig.2.1.2 (a) IMD GFS MSLP,10 meter wind, winds at 850, 500 & 200 hPa levels analysis based on 7th June 2015

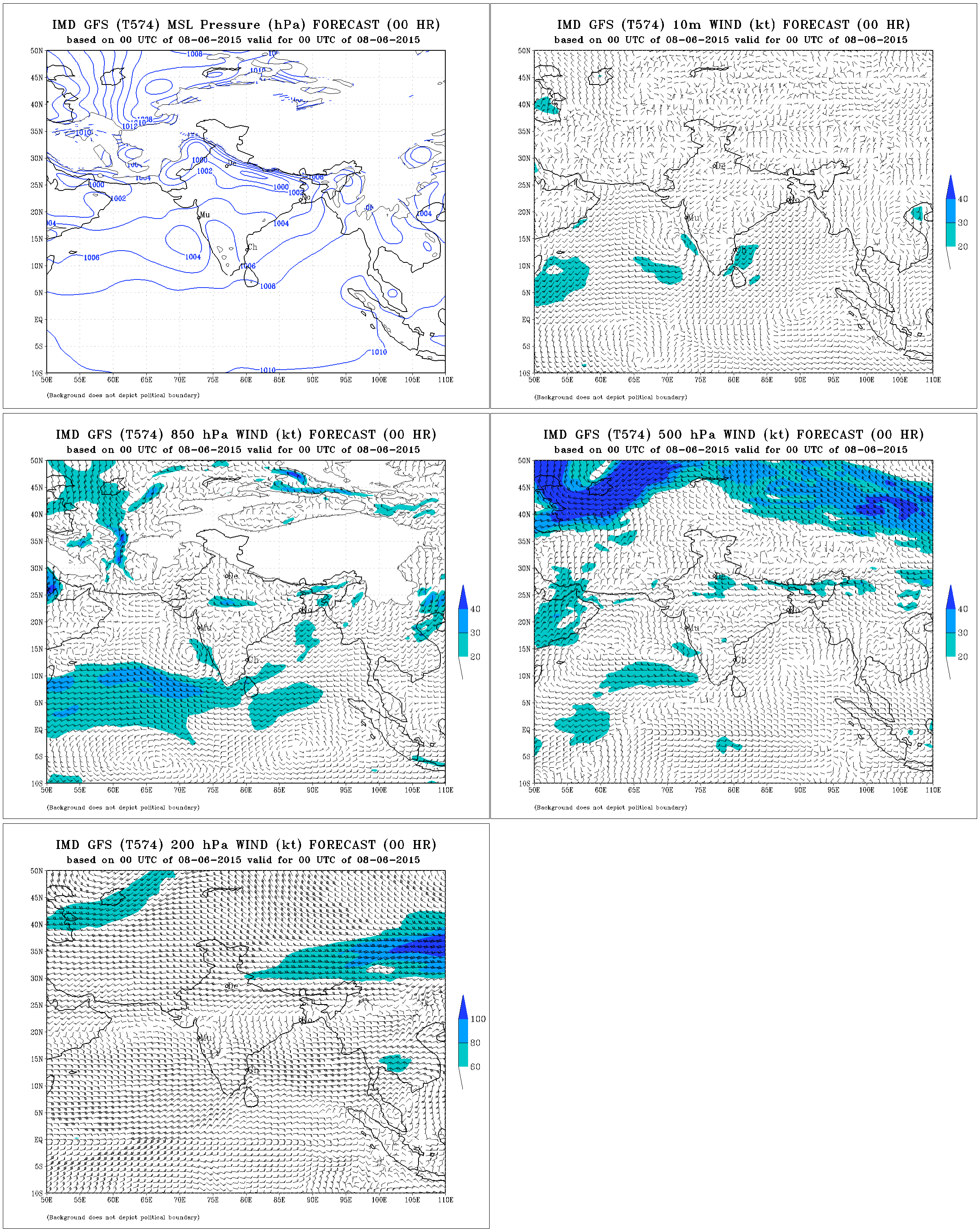


Fig.2.1.2 (b) IMD GFS MSLP,10 meter wind, winds at 850, 500 & 200 hPa levels analysis based on 8th June 2015

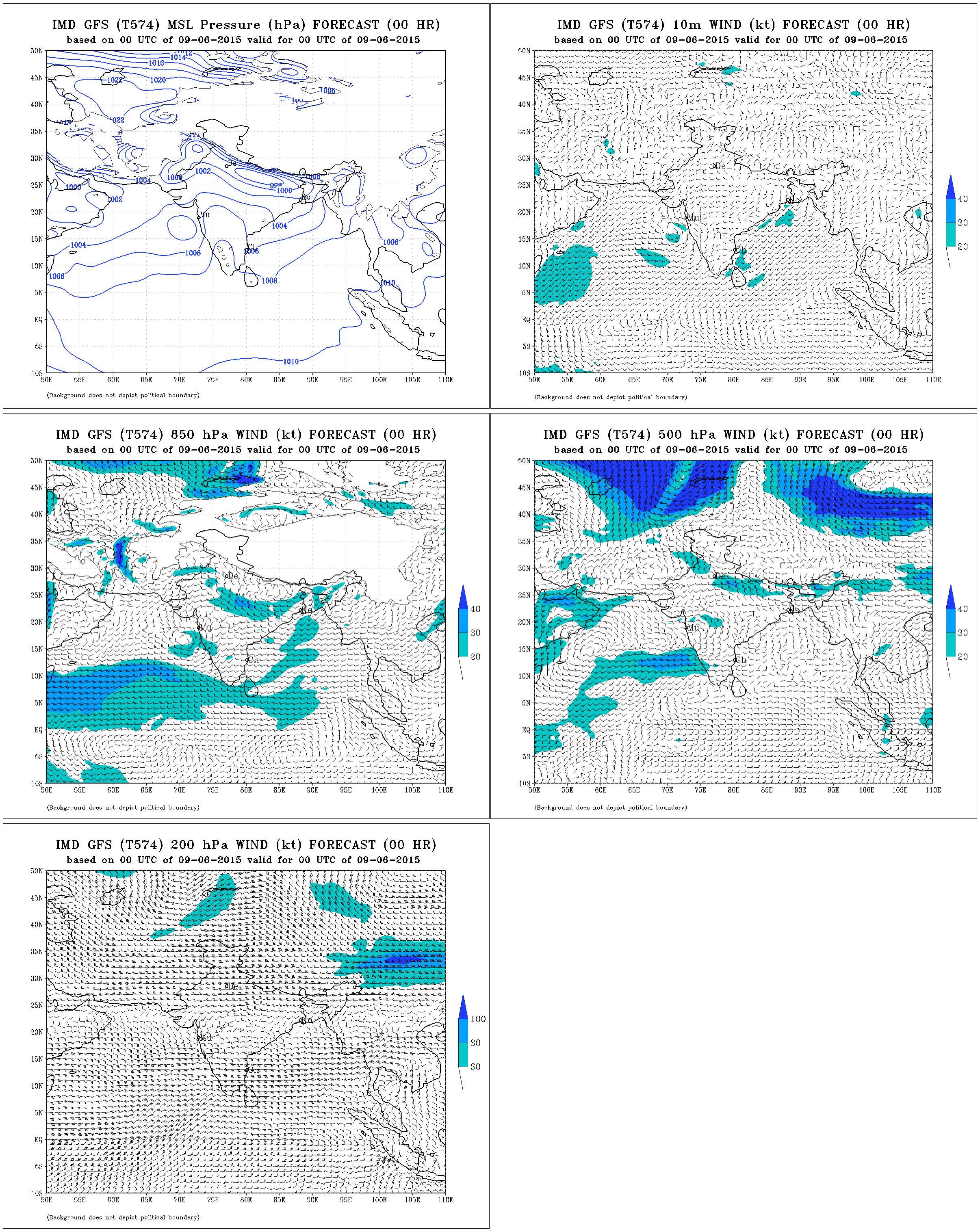


Fig.2.1.2 (c) IMD GFS MSLP, 10 meter wind, winds at 850, 500 & 200 hPa levels analysis based on 9th June 2015

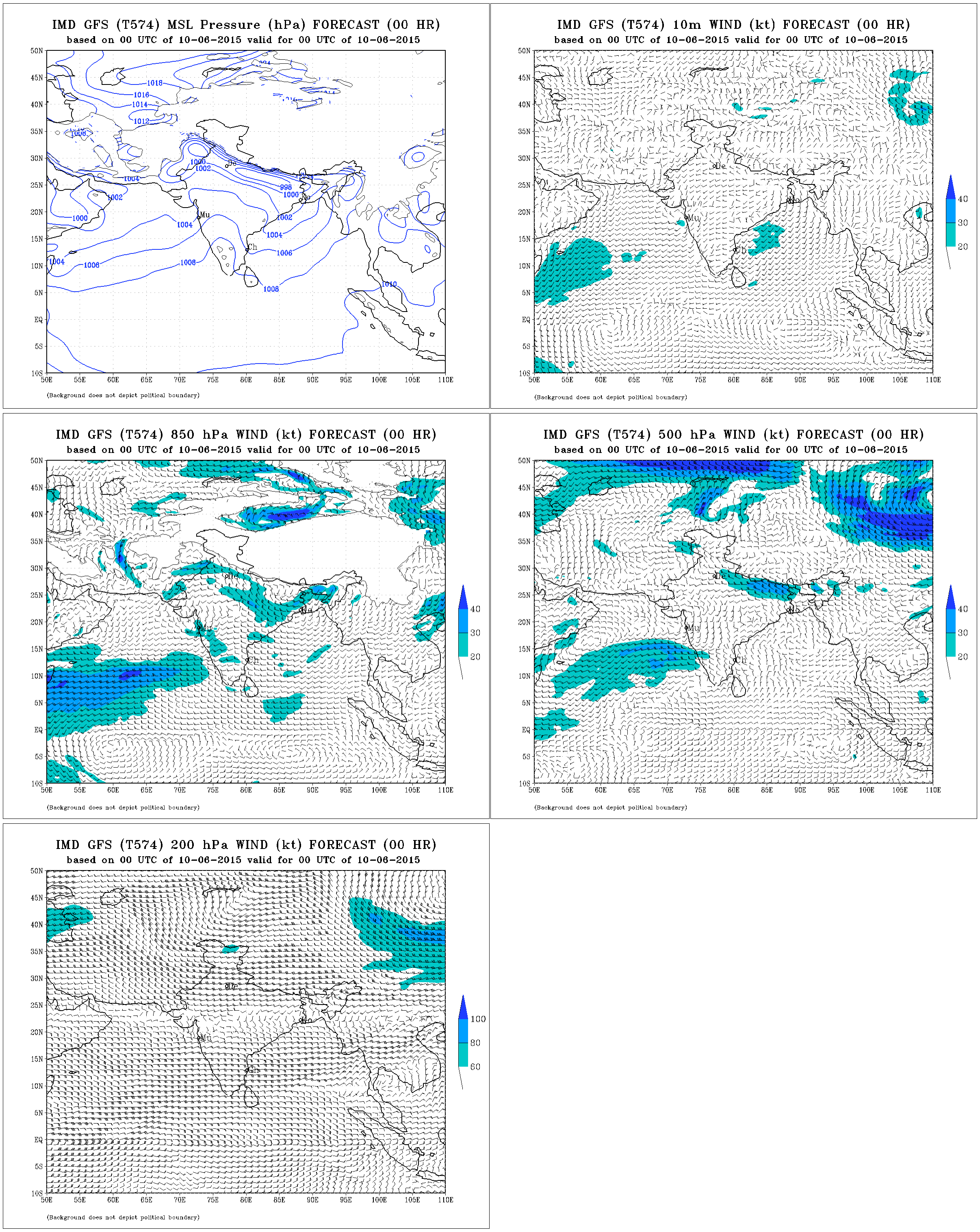


Fig.2.1.2 (d) IMD GFS MSLP, 10 meter wind, winds at 850, 500 & 200 hPa levels analysis based on 10th June 2015

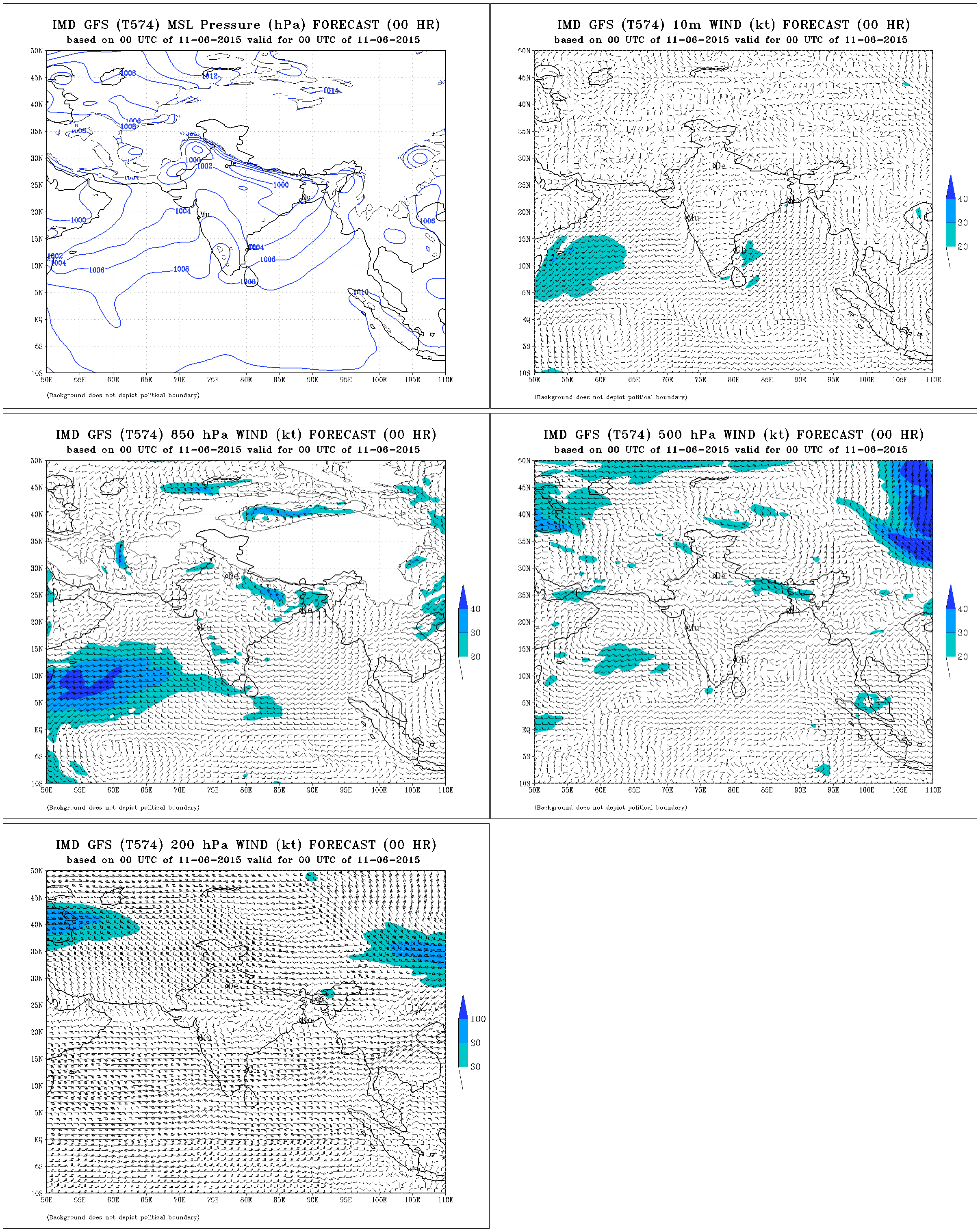


Fig.2.1.2 (e) IMD GFS MSLP, 10 meter wind, winds at 850, 500 & 200 hPa levels analysis based on 11th June 2015

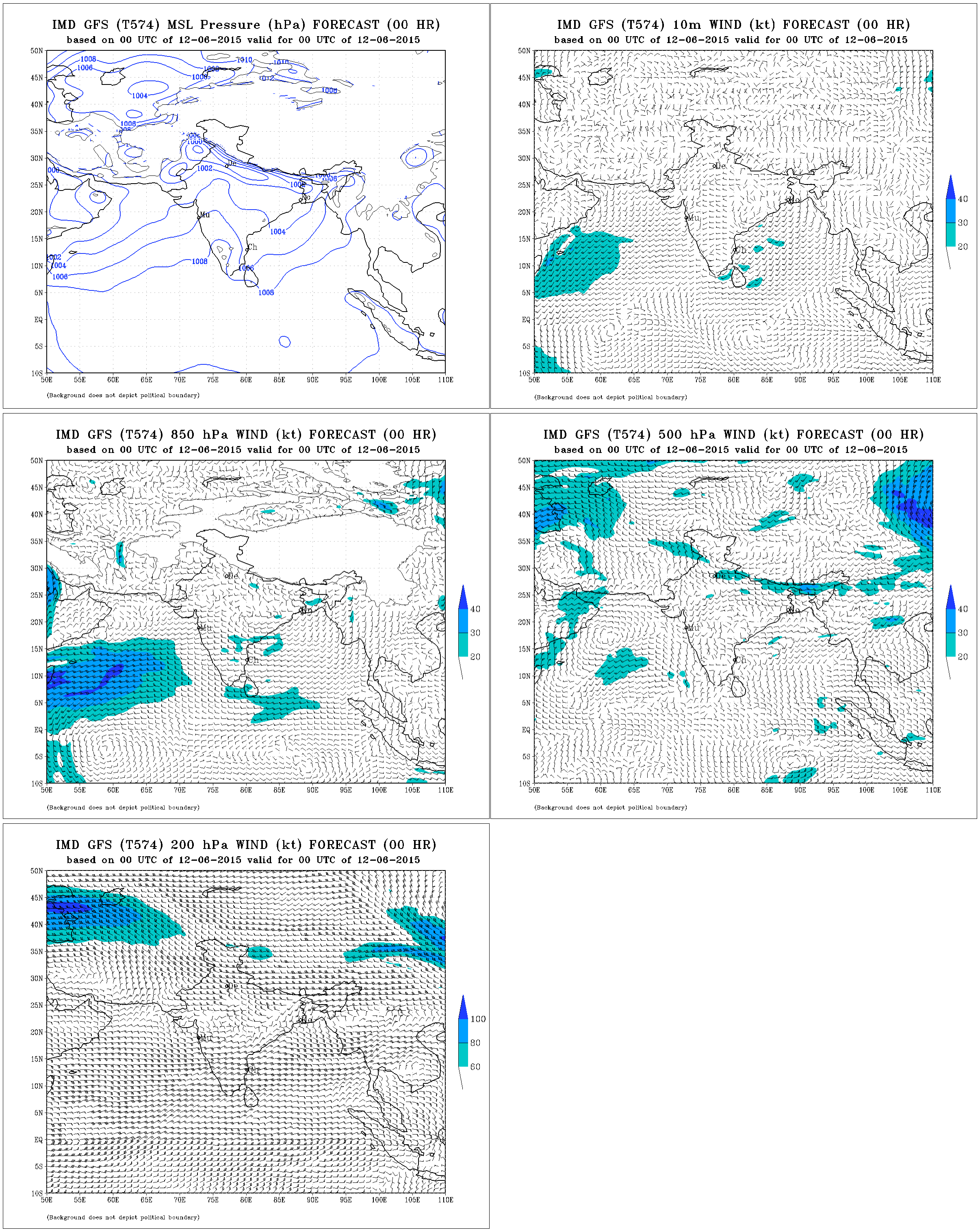


Fig.2.1.2 (f) IMD GFS MSLP, 10 meter wind, winds at 850, 500 & 200 hPa levels analysis based on 12th June 2015

2.2 Cyclonic Storm Komen over the Bay of Bengal (26 July-02 August 2015)

2.2.1 Introduction

The cyclonic storm, KOMEN over the Bay of Bengal developed from a low pressure area which lay over northeast BoB and adjoining Bangladesh & Gangetic West Bengal on 25th July evening and concentrated into a depression over the same area in the morning of 26^{th} July. It followed a semi-circular track over northeast Bay of Bengal and then crossed Bangladesh coast between Hatia and Sandwip near lat. 22.5^0N and long. 91.4^0E during 1400 and 1500 UTC of 30^{th} July. After landfall, it moved initially north-northwestwards, then westwards and west-southwestwards across Bangladesh, Gangetic West Bengal and Jharkhand. It weakened gradually into a well marked low pressure area over Jharkhand and adjoining north Odisha and north Chhattisgarh at 1200 UTC of 02^{nd} August.

The salient features of this cyclone are as follows.

i. It was the fourth system during the monsoon month of July which intensified into a CS during the satellite era (1965-2015). Of the three systems before CS Komen, the CS in July 1972 & 1973 and the CS in July 1989 crossed Odisha and Andhra Pradesh coast respectively.
ii. The CS Komen had a unique track, as it developed near Bangladesh coast, followed a semi-circular track over the northeast Bay of Bengal and finally moved northward to cross Bangladesh coast.

Brief life history, characteristic features and associated weather along with performance of numerical weather prediction models and operational forecast of IMD are presented and discussed in following sections.

2.2.2 Monitoring of CS, KOMEN

The CS KOMEN was monitored & predicted continuously since its inception by the India Meteorological Department (IMD). The forecast of its genesis (formation of Depression) on 26^{th} July., its track, intensity, point & time of landfall, as well as associated adverse weather like heavy rain, gale wind & storm surge were predicted well with sufficient lead time which helped the disaster managers to maximize the management of cyclone.

At the genesis stage, which occurred close to Bangladesh coast, the system was monitored mainly with surface observations from India, Bangladesh and Myanmar, supported by meteorological buoys and scatterometer based surface wind observations from satellite. As the system entered into the northeast Bay of Bengal moving southward away from the coast, it was monitored additionally by satellite observations 29^{th} July early morning. It was also tracked by the Doppler Weather Radar (DWR) at Khepupara and Cox's Bazar (Bangladesh) throughout its life period.

Various national and international NWP models and dynamical-statistical models including IMD and National Centre for Medium Range Weather Forecasting (NCMRWF) global and meso-scale models, dynamical statistical models for genesis and intensity were utilized to predict the genesis, track and intensity of the storm. Tropical Cyclone Module, the digitized forecasting system of IMD was utilized for analysis and comparison of various models guidance, decision making process and warning product generation.

2.2.3. Brief life history

2.2.3.1. Genesis

Under the influence of active monsoon conditions, a low pressure area formed over northeast BoB and adjoining Bangladesh & Gangetic West Bengal on 25th evening. It persisted over the same region and concentrated into a depression at 0300 UTC of 26th July near lat 22.0^{0}N and long. 90.8^{0}E, close to Bangladesh coast.

The winds were stronger in southern sector (25-30 knots) under the influence of southwest monsoon current and were about 15-20 knots in northern sector. The vertical wind shear was low (5-10 knots) around the system centre. The low level relative vorticity was about 100-150 x 10^{-5} second^{-1} and low level convergence was 40 x 10^{-5} second^{-1}. The upper level divergence was 40 x 10^{-5} second^{-1}. The region of maxima in low level vorticity, low level convergence and upper level divergence lay to the southeast of system centre. As a result, maximum convection in association with the system lay to the southeast of the system centre.

2.2.3.2. Track and intensification

Best track parameters of cyclonic storm, KOMEN over BoB (26th July-2nd August, 2015) are given in Table 2.6.1. The observed track of the system is also shown in Fig.2.1

The environmental features as mentioned in the previous section continued during 26-30th July favouring the intensification of the system to a CS, Komen. However, it could not intensify further, as it interacted with the land surface and the Ocean thermal energy was less than 50 KJ/cm^{2}, though the sea surface temperature was about 31^{0}C. The large scale feature like Madden Julian Oscillation index lay over phase 2 (west equatorial Indian Ocean with amplitude less than 1 and hence it was not favourable for intensification. There was a cyclonic circulation to the north-northeast of the CS. It helped in dry air intrusion in the CS field which inhibited further intensification.

The Depression moved slowly westwards and lay centred at 1200 UTC of 26th July near lat. 22.0^{0}N and long. 90.5^{0}E. It remained stationary there till 0300 UTC of 28th and then moved slowly southwestwards and lay centred at 1200 UTC of 28th July near lat. 21.5^{0}N and long. 90.2^{0}E. It then moved southeastwards, intensified into a Deep Depression and lay centred at 0000 UTC of 29th July near lat. 21.0^{0}N and long. 91.0^{0}E. The Deep Depression moved east-northeastwards initially and then north-northeastwards till 1200 UTC of 29th July. It then moved nearly northward, intensified into a CS, KOMEN and lay centred at 1800 UTC of 29th July near lat. 21.6^{0}N and long. 91.4^{0}E. It continued to move nearly northwards and crossed Bangladesh coast between Hatia and Sandwip (near lat. 22.5^{0}N and long. 91.4^{0}E) during 1400 and 1500 UTC of 30th July. After the landfall it moved north-northwestwards and gradually weakened into a Deep Depression at 2100 UTC of 30th July over Bangladesh near lat. 23.0^{0}N and long. 91.0^{0}E,it then moved west-northwestwards and further weakened into a Depression at 1200 UTC of 31st July and lay centred over Bangladesh and adjoining Gangetic West Bengal near lat. 23.1^{0}N and long. 89.5^{0}E. It continued its west-northwestward movement till 1200 UTC of 1st August and then moved initially westwards and then west-southwestwards and weakened into a well marked low pressure area over Jharkhand and adjoining north Odisha and north Chhattisgarh at 1200 UTC of 02nd August.

The system was steered by the low to middle level monsoon circulation leading to a semi-circular path till 29th July. Thereafter, the anti-cyclonic circulation to the east of the system centre located over Myanmar and adjoining Bangladesh helped in providing northward steering current. As a result the CS, Komen moved nearly northward on 30th July till landfall. After that the system was steered by the Tibetan anti-cyclonic circulation and hence moved westwards. The anti-cyclonic circulation to the west of the system centre limited the translational speed of the cyclone towards the west on 31st July and further pushed the system west-southwestwards on 2nd August.

During the initial period of the CS, Komen, there was a deep depression over Gujarat, which moved north-northwestwards across Rajasthan and weakened gradually, while the depression over northeast Bay of Bengal moved south-southeastward and strengthened gradually. It needs therefore further investigation to find out the interaction, if any, between the deep depression over Gujarat/ Rajasthan and the deep depression over northeast Bay of Bengal.

Table 2.2.1 Best track parameters of cyclonic storm, KOMEN over the Bay of Bengal during 26 July- 2 August, 2015

Date	Time (UTC)	Centre lat.^{0} N/ long. ^{0} E	C.I. NO.	Estimated Central Pressure (hPa)	Estimated Maximum Sustained Surface Wind (kt)	Estimated Pressure drop at the Centre (hPa)	Grade
26/07/2015	0000	22.0/90.8	1.5	994	20	3	D
	0300	22.0/90.8	1.5	994	20	3	D
	0600	22.0/90.5	1.5	994	20	3	D
	1200	22.0/90.5	1.5	994	20	3	D
	1800	22.0/90.5	1.5	994	20	3	D
27/07/2015	0000	22.0/90.5	1.5	994	20	3	D
	0300	22.0/90.5	1.5	994	25	4	D
	0600	22.0/90.5	1.5	994	25	4	D
	1200	22.0/90.5	1.5	994	25	4	D
	1800	22.0/90.5	1.5	994	25	4	D
28/07/2015	0000	22.0/90.5	1.5	994	25	4	D
	0300	22.0/90.5	1.5	994	25	4	D
	0600	21.8/90.3	1.5	994	25	4	D
	1200	21.5/90.2	1.5	994	25	4	D
	1800	21.3/90.6	1.5	992	25	4	D
29/07/2015	0000	21.0/91.0	2.0	990	30	5	DD
	0300	21.1/91.0	2.0	990	30	5	DD
	0600	21.2/91.1	2.0	990	30	5	DD
	1200	21.5/91.4	2.0	988	30	6	DD

	1800	21.6/91.4	2.5	986	35	7	CS
30/07/2015	0000	21.7/91.4	2.5	986	35	7	CS
	0300	22.0/91.4	2.5	986	35	7	CS
	0600	22.2/91.4	2.5	986	40	8	CS
	0900	22.3/91.4	2.5	986	40	8	CS
	1200	22.4/91.4	2.5	988	35	7	CS
	Crossed Bangladesh coast near longitude 91.4^{0}E during 1400-1500 UTC						
	1500	22.6/91.3	-	988	35	7	CS
	1800	22.8/91.1	-	988	35	7	CS
	2100	23.0/91.0	-	988	30	6	DD
31/07/2015	0000	23.1/90.0	-	990	30	5	DD
	0300	23.1/90.0	-	990	30	5	DD
	0600	23.1/89.8	-	992	30	5	DD
	1200	23.1/89.5	-	994	25	4	D
	1800	23.1/89.4	-	994	25	4	D
01/08/2015	0000	23.2/89.2	-	994	20	4	D
	0300	23.2/89.2	-	994	20	4	D
	0600	23.5/88.8	-	994	20	4	D
	1200	23.8/88.4	-	994	20	4	D
	1800	23.8/87.5	-	994	20	4	D
02/08/2015	0000	23.8/86.7	-	996	20	3	D
	0300	23.5/86.0	-	996	20	3	D
	0600	23.3/85.7	-	996	20	3	D
	0900	23.1/85.5	-	996	20	3	D
	1200	Well Marked Low over Jharkhand and adjoining north Odisha and north Chhattisgarh					

2.2.3.3. Maximum Sustained Surface Wind speed and estimated central pressure:

The MSW in association with a cyclone affecting Indian coasts is defined as the average surface wind speed over a period of 3 minutes measured at a height of 10 meters. The MSW is either estimated by the remotely sensed observations or recorded by the surface based instruments. As the CS, Komen developed over northeast Bay of Bengal and crossed Bangladesh coast near long. 91.4^{0}E, the surface observations as well as radar and satellite observations played crucial role in determining the MSW. The highest MSW has been estimated as 40 knots. However, Teknaf (Bangladesh) reported 55 knots (in the southeastern sector of the CS, Komen) in the early hours of 30th July for a short period. It reported 76 kmph (40 kts) at 0600 UTC of 30th July. Maungdaw (48061) and Sittwe (47062) which lay to the southeast of the centre of the cyclonic storm reported maximum wind of 67 kt at 2300 UTC and 58 kt at 0400 UTC of 30th July respectively which may be due to the squall in association with the .cyclonic storm. The lowest estimated central pressure has been 986 hPa. The MSLP of about 986.5 hPa has been reported from southeastern coast of Bangladesh, when the CS was moving northward close to that coast.

2.2.4 Climatological aspects

Climatologically, during the monsoon month of July, low pressure systems (LPS) forming over the BoB do not intensify into tropical cyclones as the mean area of formation lies over the head Bay of Bengal which is very close to land and the mean vertical wind shear is quite high. During the satellite era of last 50 years period (1965-2015) over BOB, only three LPS intensified into cyclones. The tracks of these three cyclones are shown in Fig. 2.6.1. All these three systems crossed coast as a CS. All the three systems, intensified into CS and maintained the intensity of CS for a short duration of time for about a day, tracked along the climatological track of west-northwest to northwestwards towards Odisha and north Andhra Pradesh coasts before landfall.

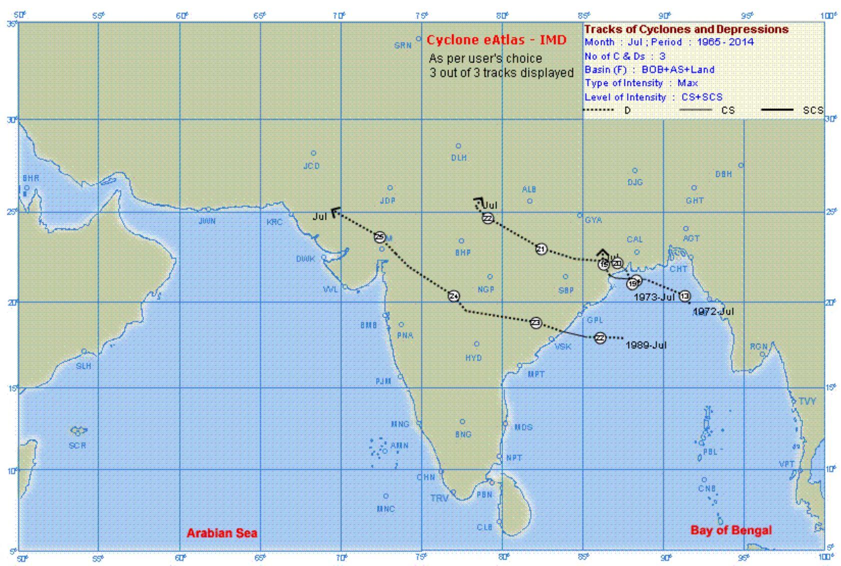


Fig. 2.2.1 Tracks of tropical cyclones over BOB in the month of July during the period 1965-2015

2.2.5 Features observed through satellite

Half hourly Kalpana-1 and INSAT-3D imageries were utilised for monitoring of CS, Komen. Satellite imageries of international geostationary satellites Meteosat-7 and MTSAT and microwave & high resolution images of polar orbiting satellites DMSP, NOAA series, TRMM, Metops were also considered. Typical satellite INSAT-3D imageries (visible, IR, IRBD and enhanced colour imageries) of CS Komen representing the life cycle of the cyclone are shown in Fig.2.6.2- 2.6.5

According to INSAT-3D imageries and products, the system was seen as a low level cyclonic circulation on 26th July when the system was declared as a depression based on synoptic observations. It got organized on 27th and acquired shear pattern with T 1.0 at 27/0300 UTC and the intensity was increased to T 1.5 at 28/0300 UTC. The distance between centre and cloud mass imagery was 100 km and the cloud mass was sheared to the southeast of the centre of low level circulation. The intensity was upgraded to T2.5 at 29/2100 UTC corresponding to 35 knots. At 31/0300 UTC, it indicated that the storm was over land.

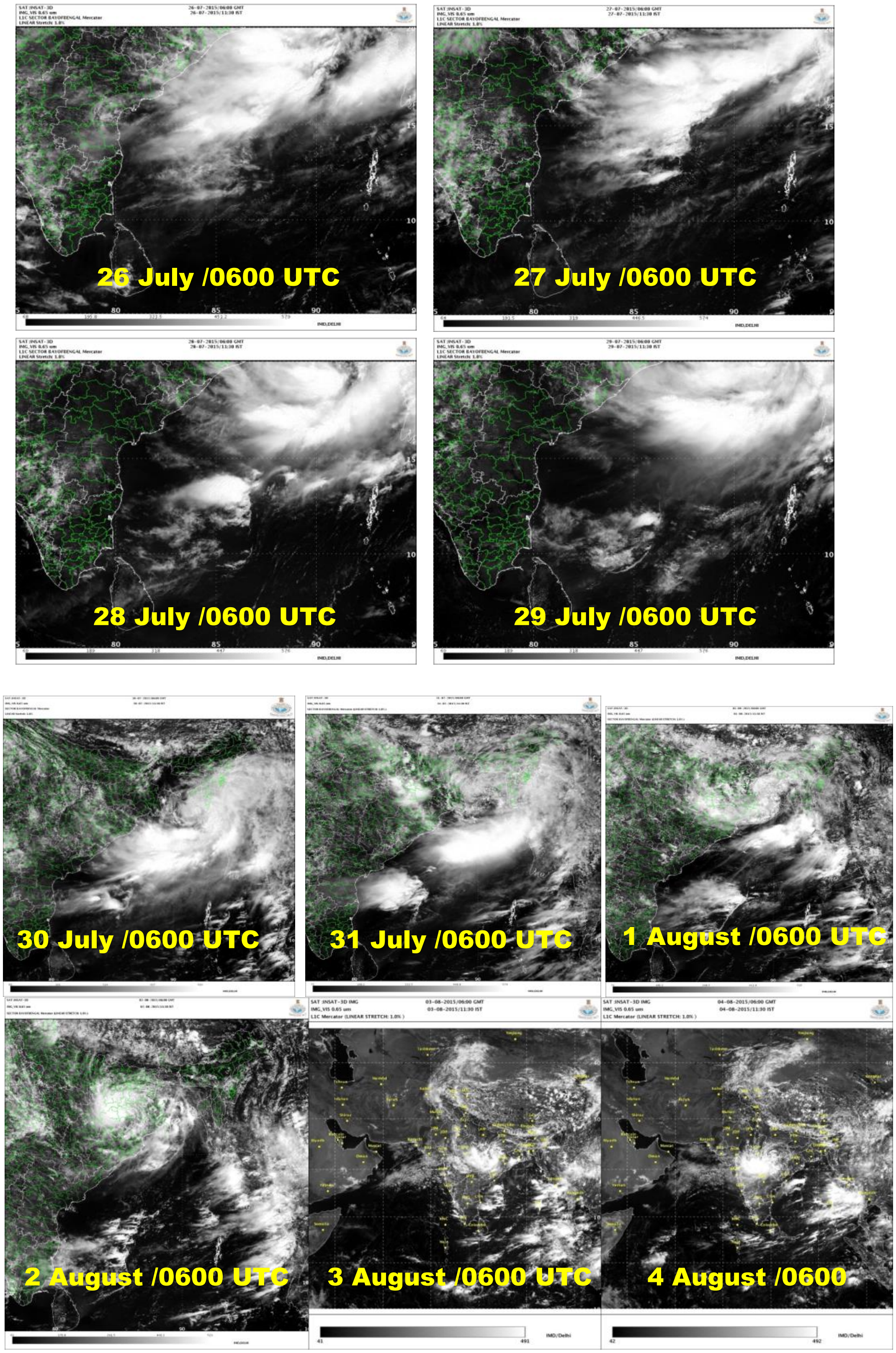


Fig2.2.2 (a)INSAT-3D Visible imageries of CS Komen over Bay of Bengal during 26–29 July 2015

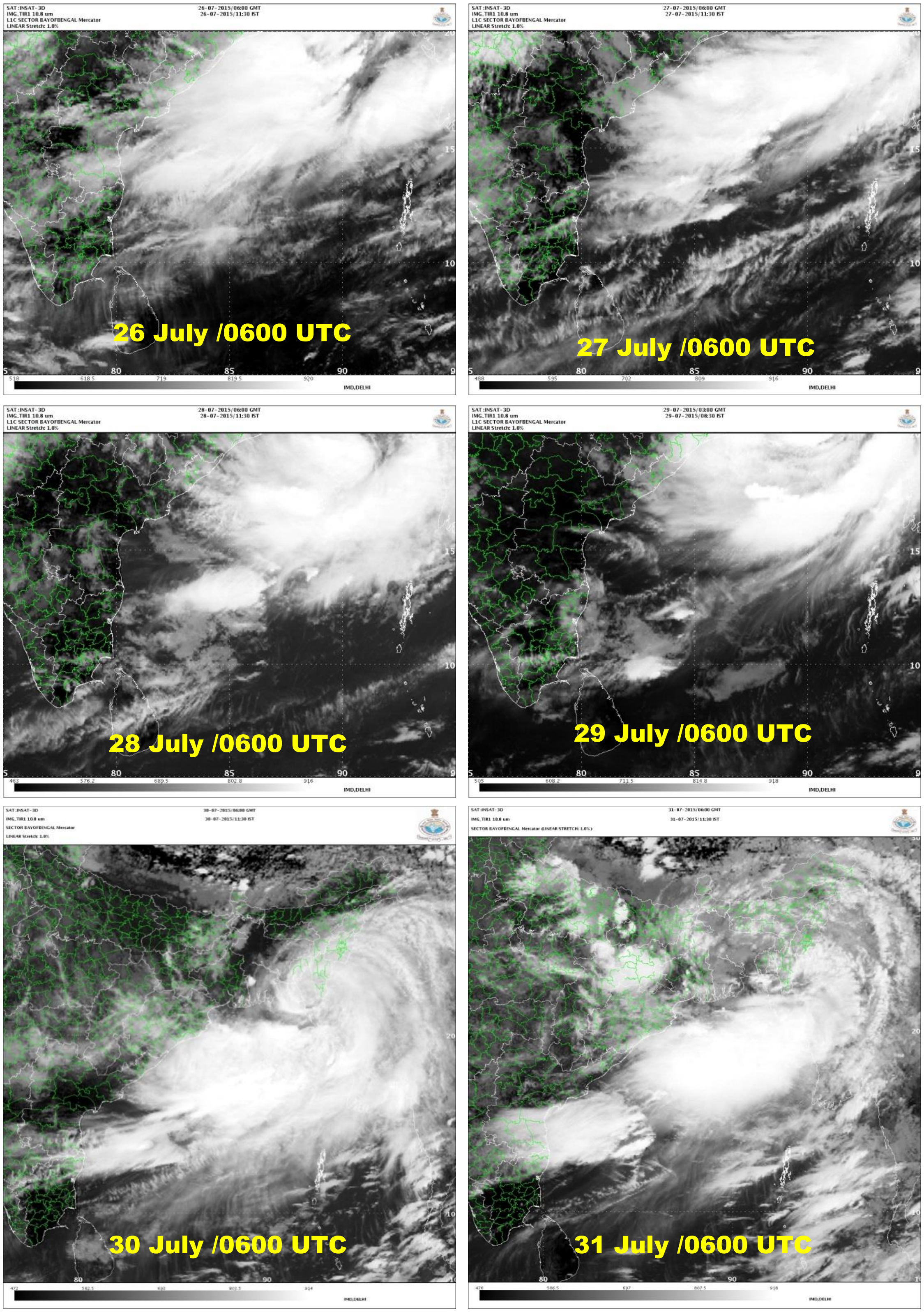


Fig. 2.2.3 (b) INSAT-3D IR imageries of CS Komen over Bay of Bengal during 26–31 July 2015

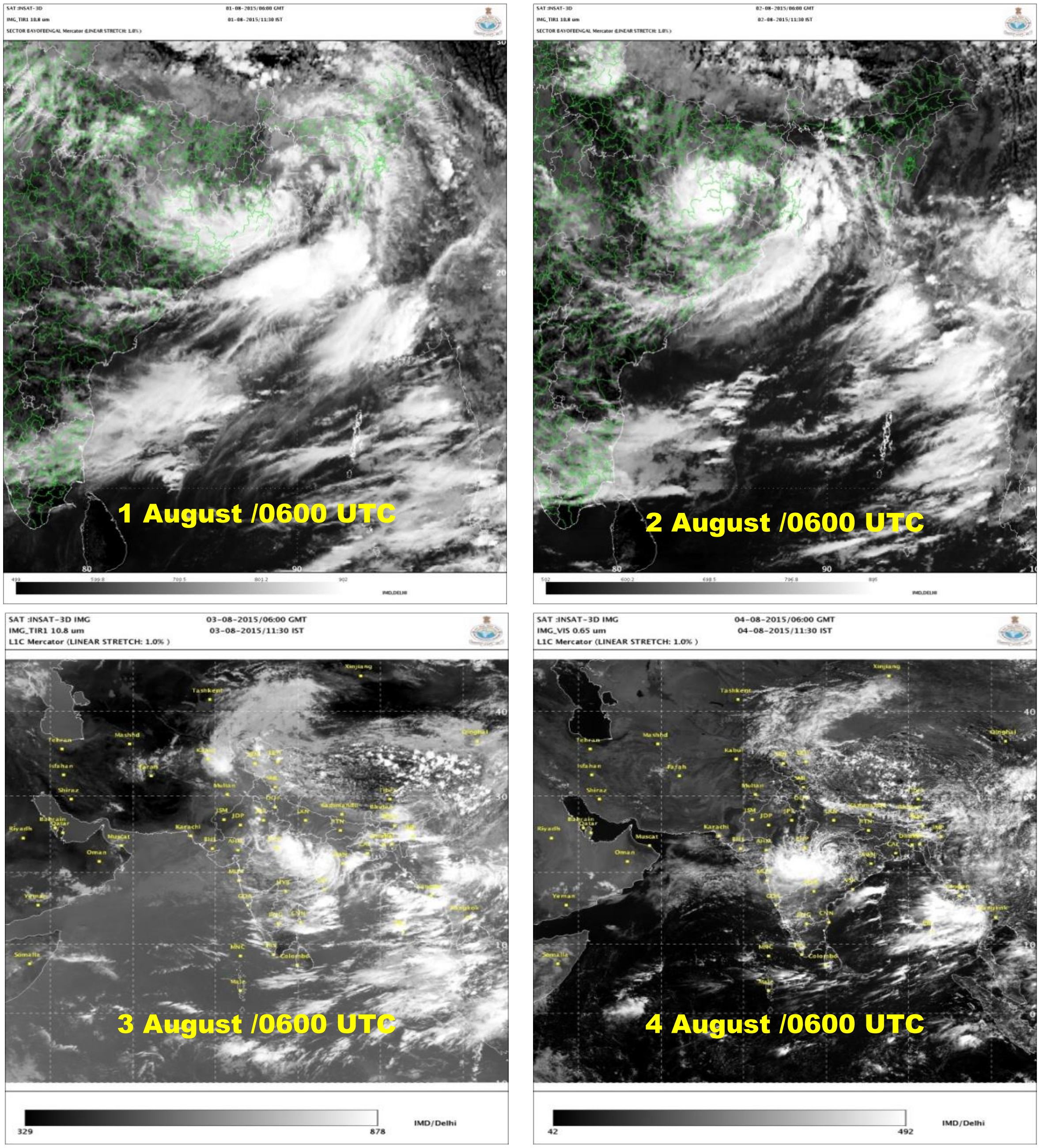


Fig. 2.2.3 (b) contd. INSAT-3D IR imageries of CS Komen over Bay of Bengal during 1 – 4 August 2015

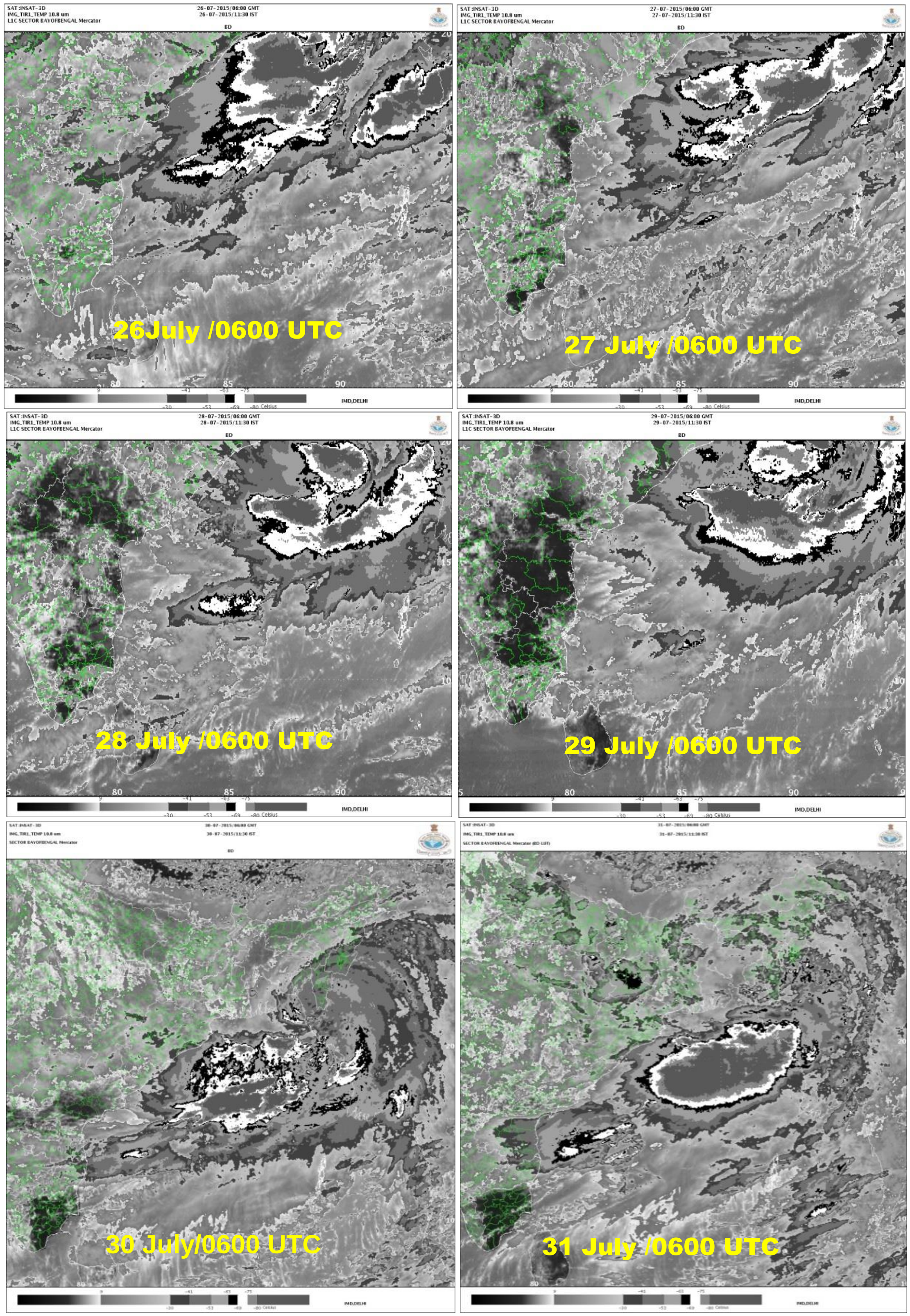


Fig. 2.2.4 (a) INSAT-3D enhanced IR imageries of CS Komen over Bay of Bengal during 26 July – 4 August 2015

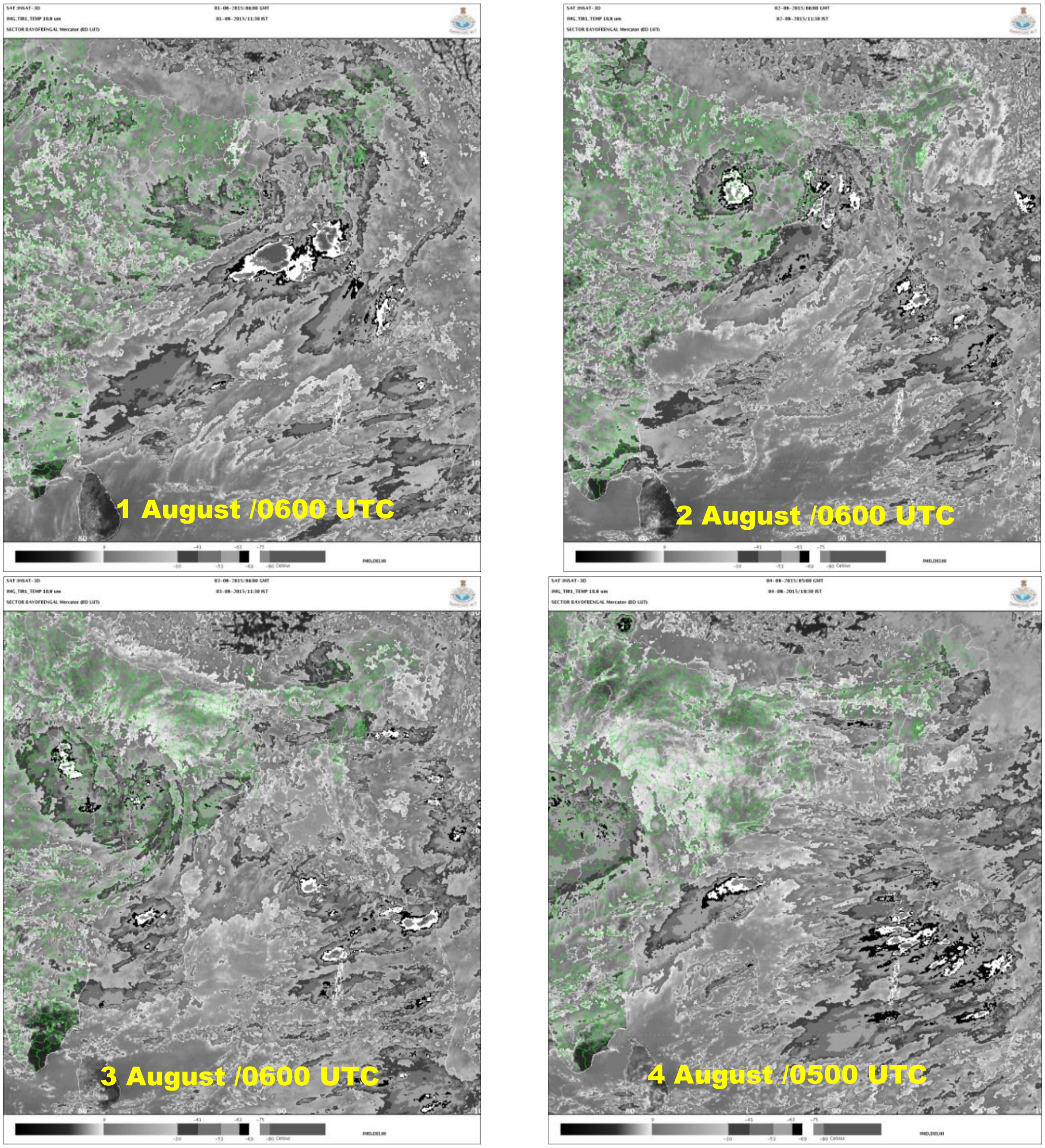


Fig. 2.2.4 (b) contd. INSAT 3D enhanced IR imageries of CS Komen over Bay of Bengal during 26 July – 4 August 2015

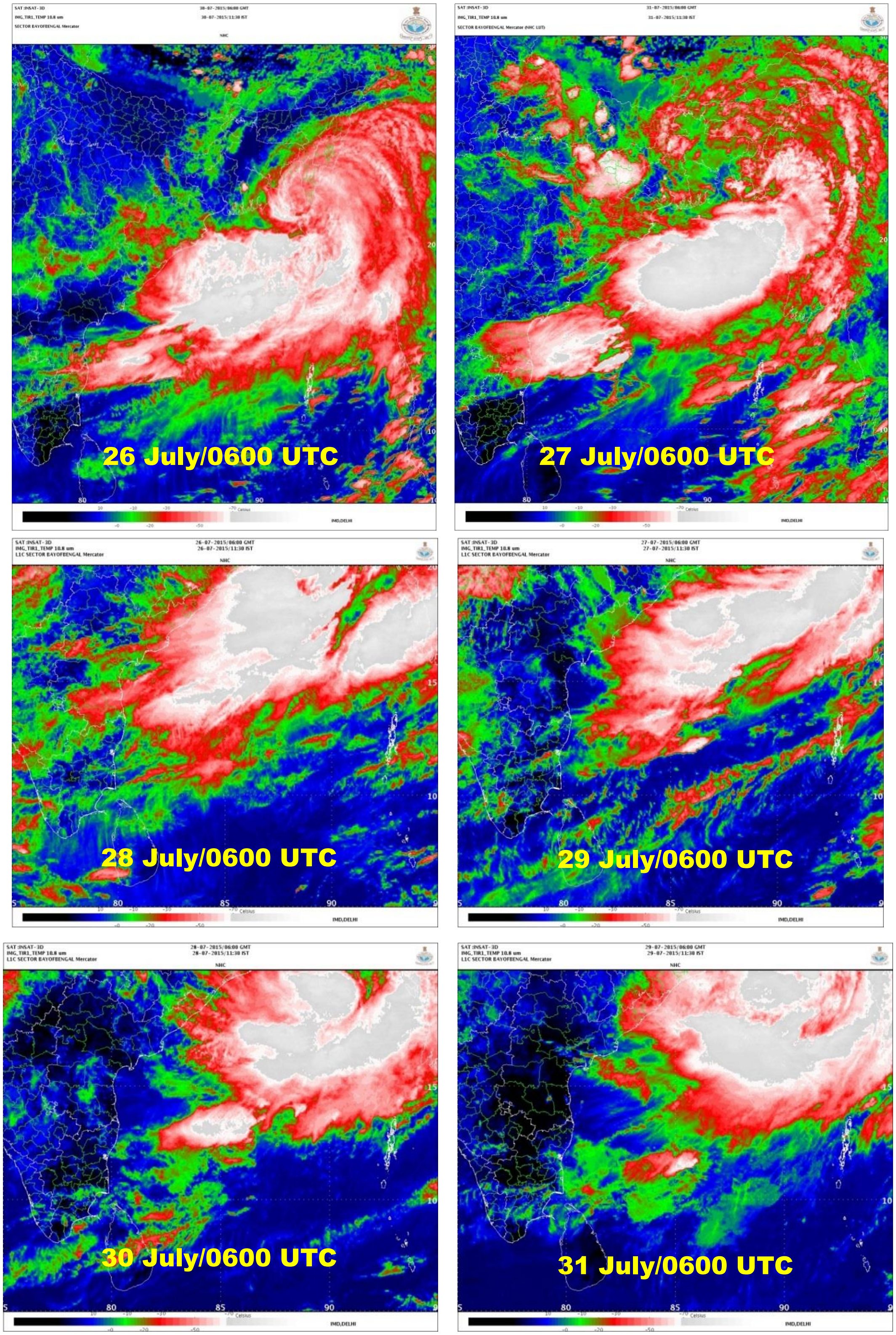


Fig. 2.2.5 (a) Enhanced colour INSAT-3D imageries of CS Komen over Bay of Bengal during 26–31July 2015

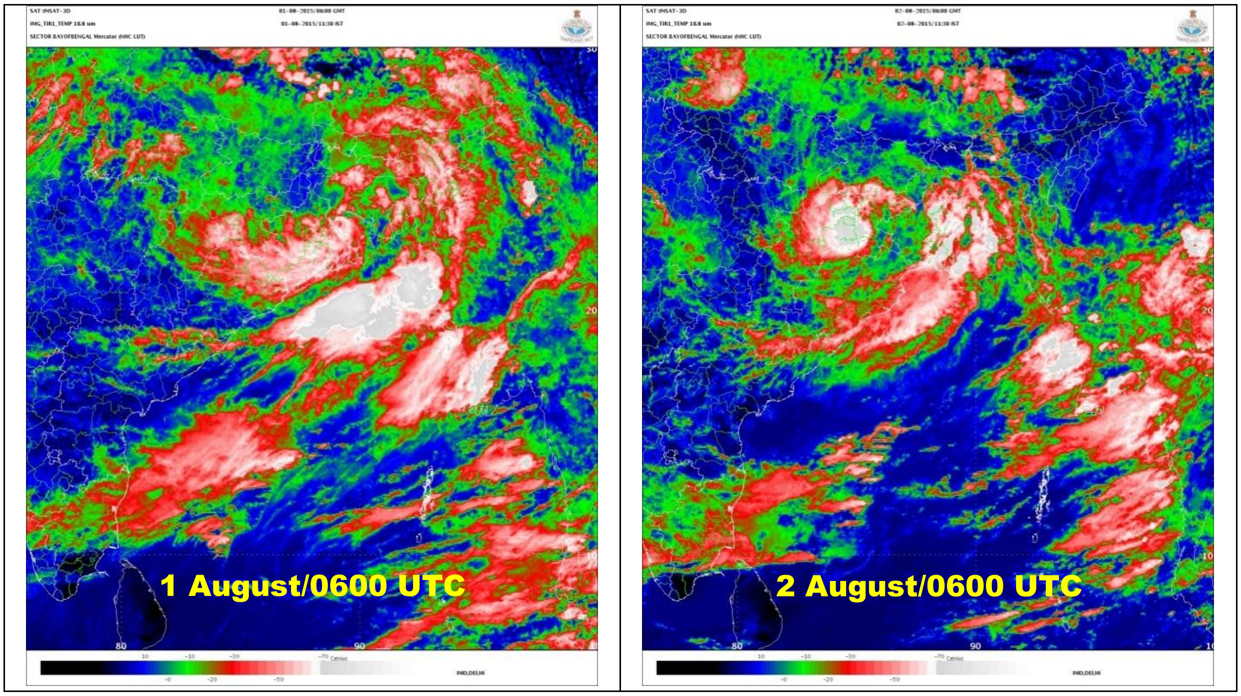


Fig. 2.2.5 (b) contd. Enhanced colour INSAT-3D imageries of CS Komen over Bay of Bengal during 1–2 August 2015

2.2.6. Features observed through Radar

On 29th and 30th, when the system was well within the radar range of DWRs at Cox's Bazar and Khepupara (Bangladesh), it was tracked continuously by these radars. The system showed spiral band structure with an ill-defined eye. The DWR observations from Khepupara and Cox's Bazar indicated well defined circulation with strong banding feature in southern semi circle similar to the features observed through satellite. There was weak banding in the northern sector, as long as the CS over the Sea.

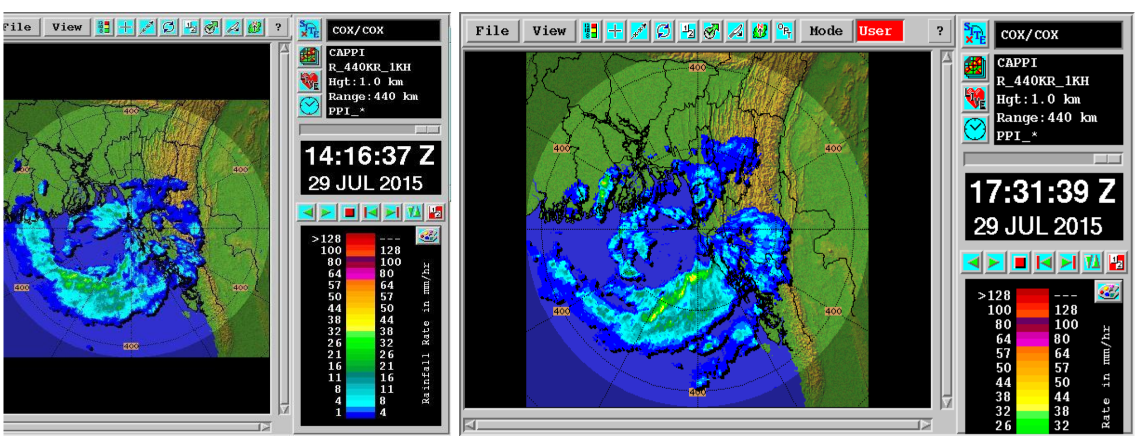


Fig. 2.2.6 (a) CAPPI imageries of Cox's Bazar (Bangladesh) on 29th

When the system was over the sea, maximum convection was observed in the southeastern sector. However, as the system approached the coast and after coastal crossing, convection shifted to the southwestern sector. Fig.2.6.6 shows the Constant Altitude Plan Position

Indicator (CAPPI) imageries of (a) Cox's Bazar (at about 14 & 17 UTC of 29th and 10 and 12 UTC of 30th) and (b) Khepupara radars (at about 0530 and 15 UTC of 29th and 1130 UTC of 30th).

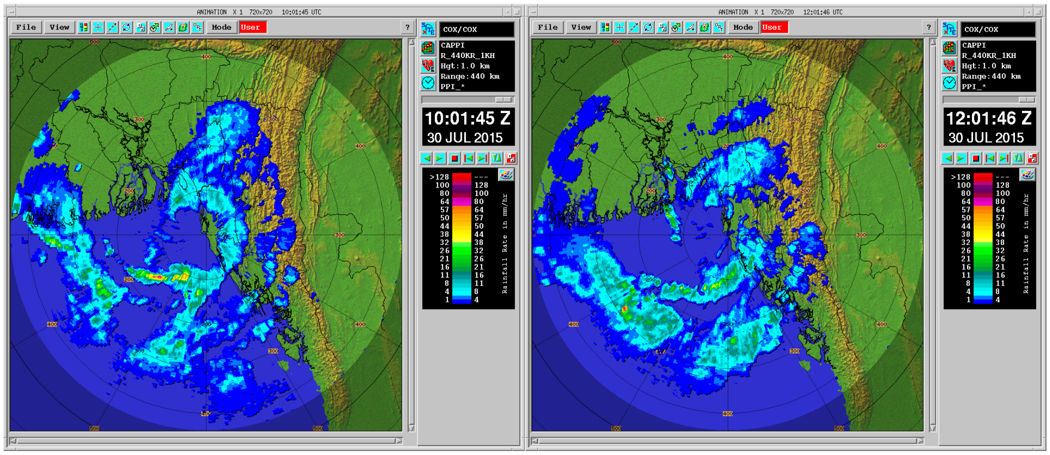


Fig. 2.2.6 (a) contd. CAPPI imageries of Cox's Bazar (Bangladesh) at about 1000 and 1200 UTC of 30th July

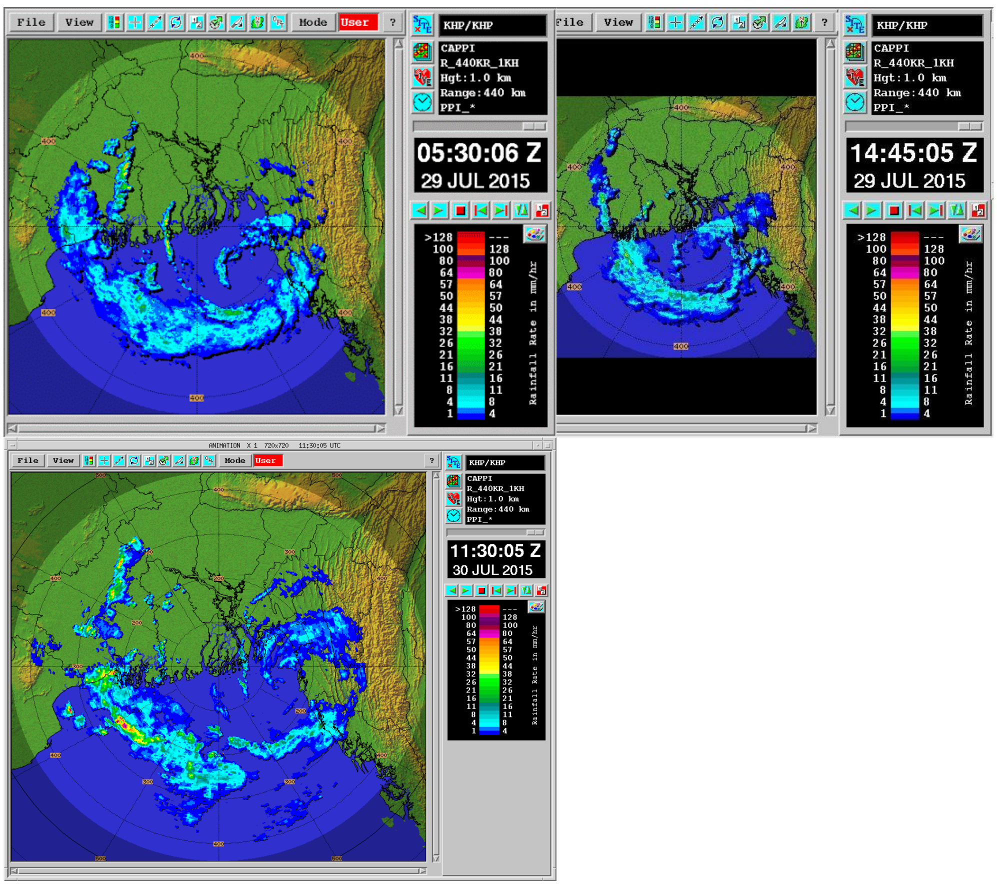


Fig.. 2.2.6 (b) CAPPI imageries of Khepupara (Bangladesh) of 29th and 30th July

2.2.7. Dynamical features

To analyse the dynamical features, the IMD-GFS model analyses based on the initial conditions of 0000 UTC of 27-31 July are shown in Fig 2.2.7 (a-c). It is observed that the model could very well simulate the genesis and intensification though there was under-estimation of the intensity. Further it could simulate the track well and establish the interaction between the depression over Rajasthan and CS, Komen over the Bay of Bengal. It could simulate the gradual north-northwest movement and later the northeastward movement of the Depression over Rajasthan along with gradual initial intensification and weakening in the later stage during the period of 27-31 July 2015. During the same period, the opposite trend in intensification and movement of CS, Komen could also be simulated by the model. Further, the model could simulate the higher wind speed in the southern sector and relatively less wind in the northern sector of Komen, while it was over the sea. However, the unique track showing the semi-circular movement over the Bay of Bengal could not be simulated very well. Further, the model could not simulate the cyclonic circulation lying to the northeast of the system centre on 29th and 30th July, which helped in dry air incursion into the system and hence limited its further intensification. It also failed to simulate the anti-cyclonic circulation in middle and upper tropospheric level over Myanmar and Bangladesh which helped in steering the system northward on 30th July.

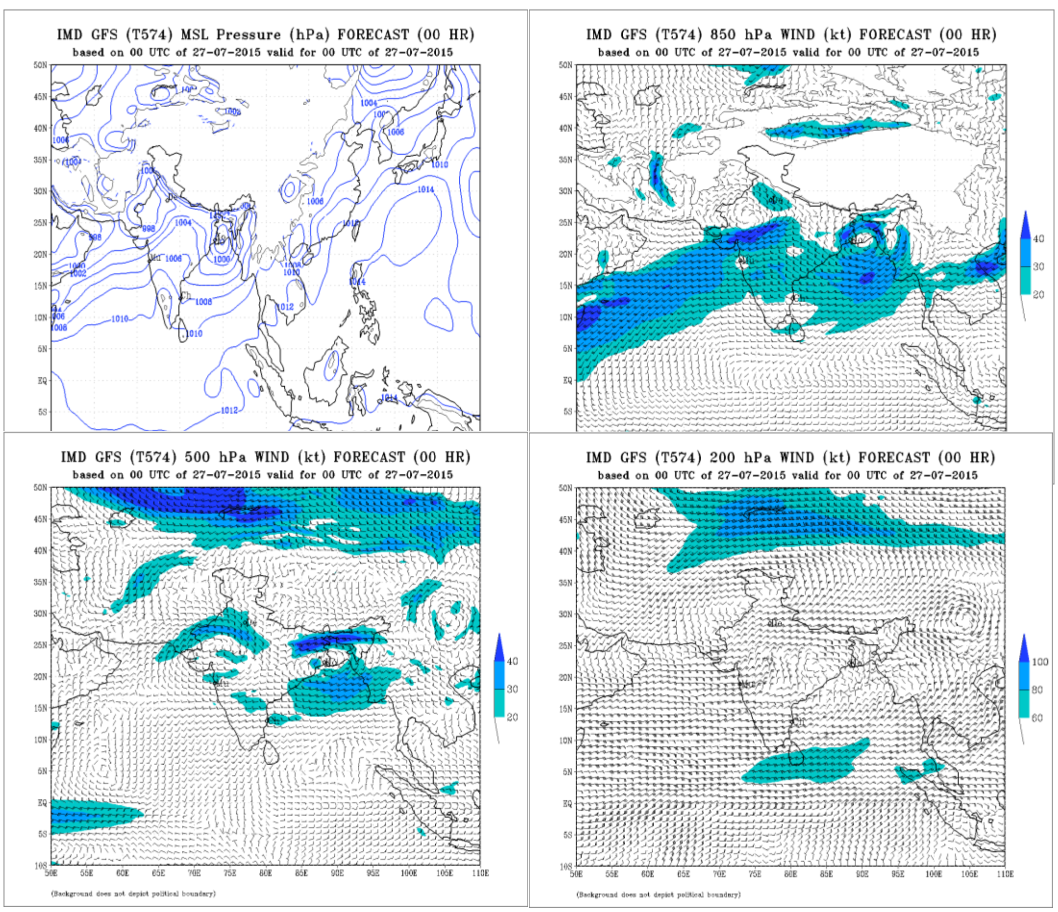


Fig.2.2.7 (a)IMD-GFS analyses of MSLP, winds at (a) 850 hPa, (b) 500 hPa and (c) 200 hPa levels based on 0000 UTC of 27th July, 2015

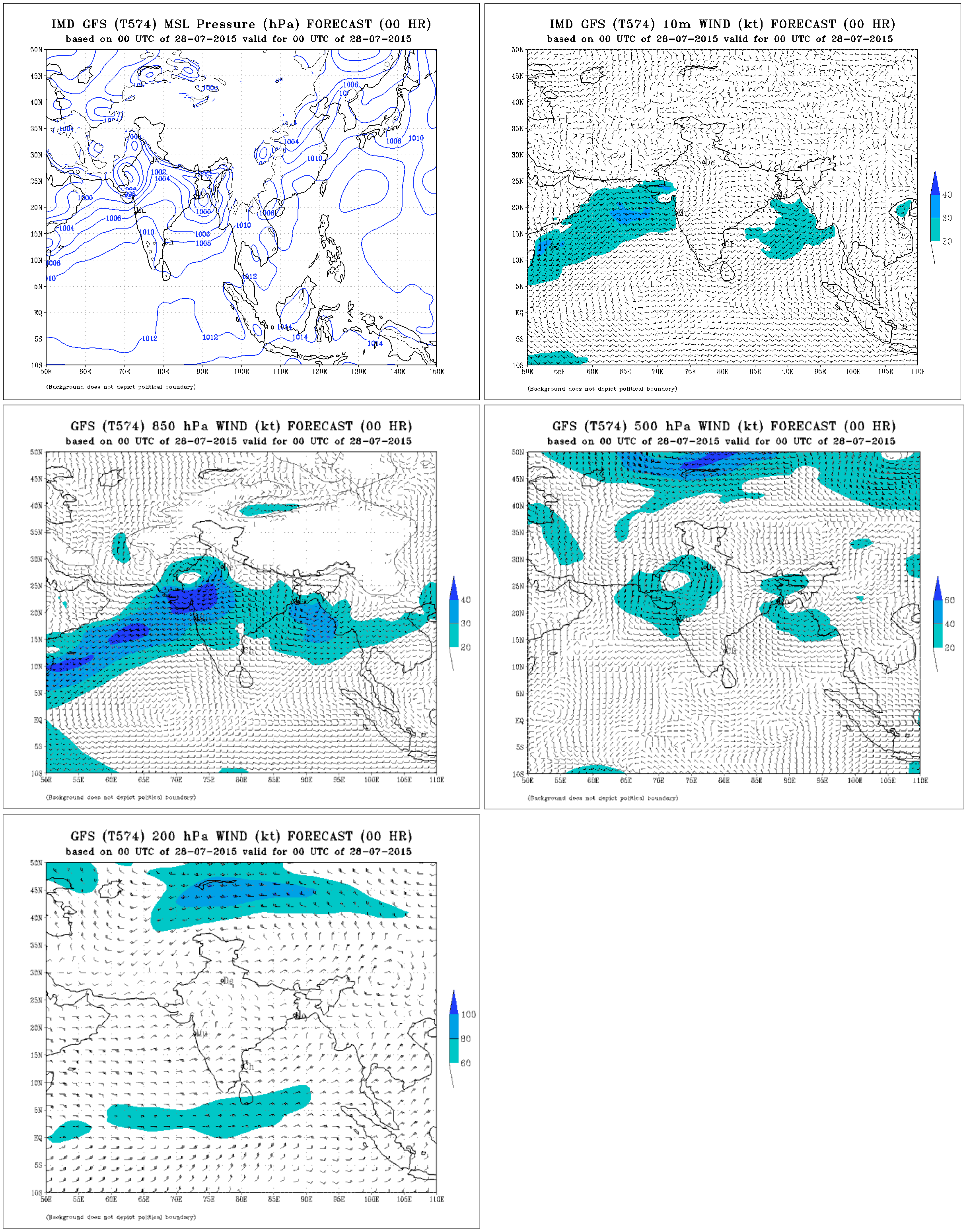


Fig2.2.7 (b)IMD-GFS analyses of MSLP, 10 metre wind, winds at (a) 850 hPa, (b) 500 hPa and (c) 200 hPa levels based on 0000 UTC of 28th July, 2015

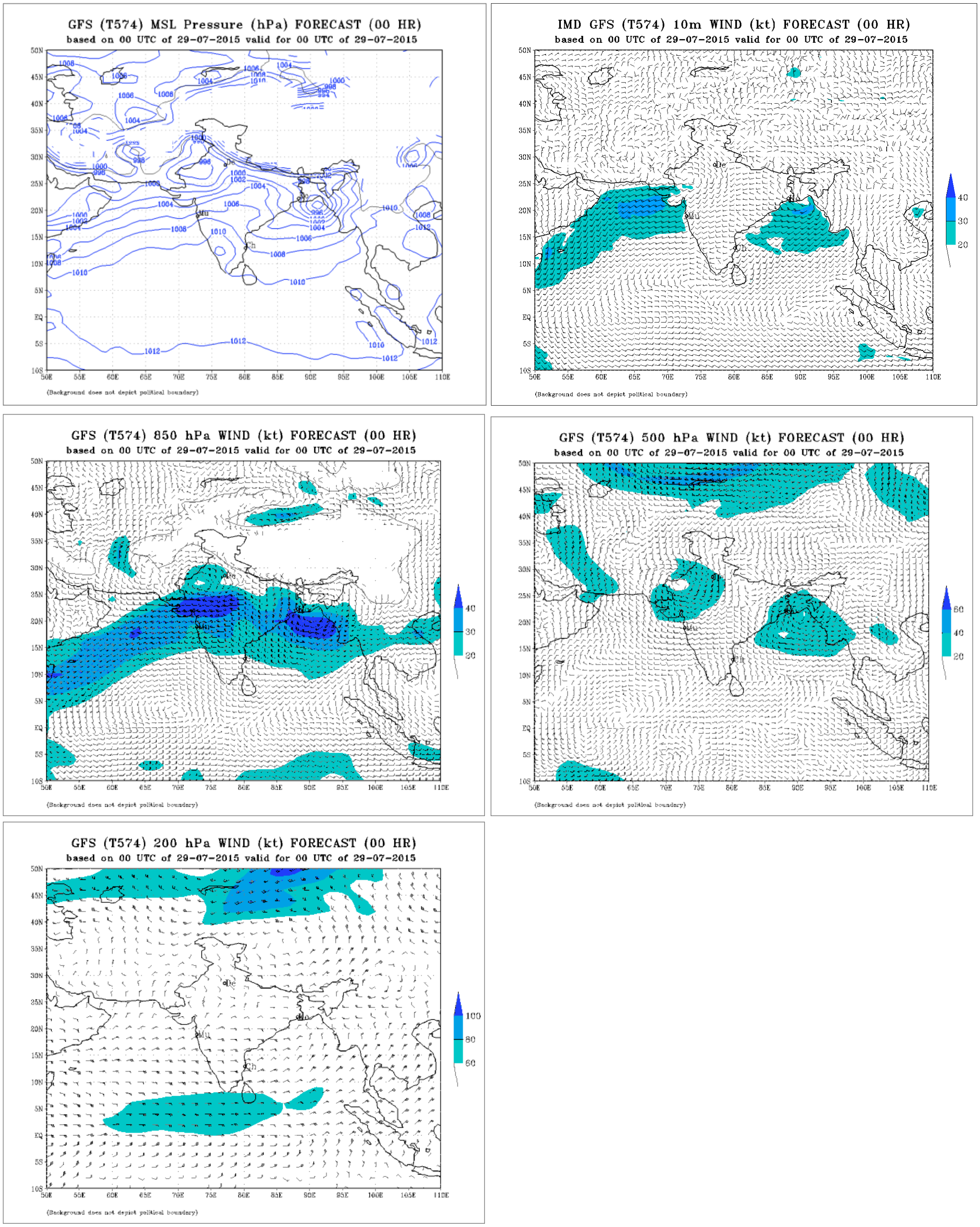


Fig 2.2.7 (c) IMD-GFS analyses of (a) MSLP, 10 metre wind and winds at (b) 850 hPa, (c) 500 hPa& (d) 200 hPa levels based on 0000 UTC of 29th July, 2015

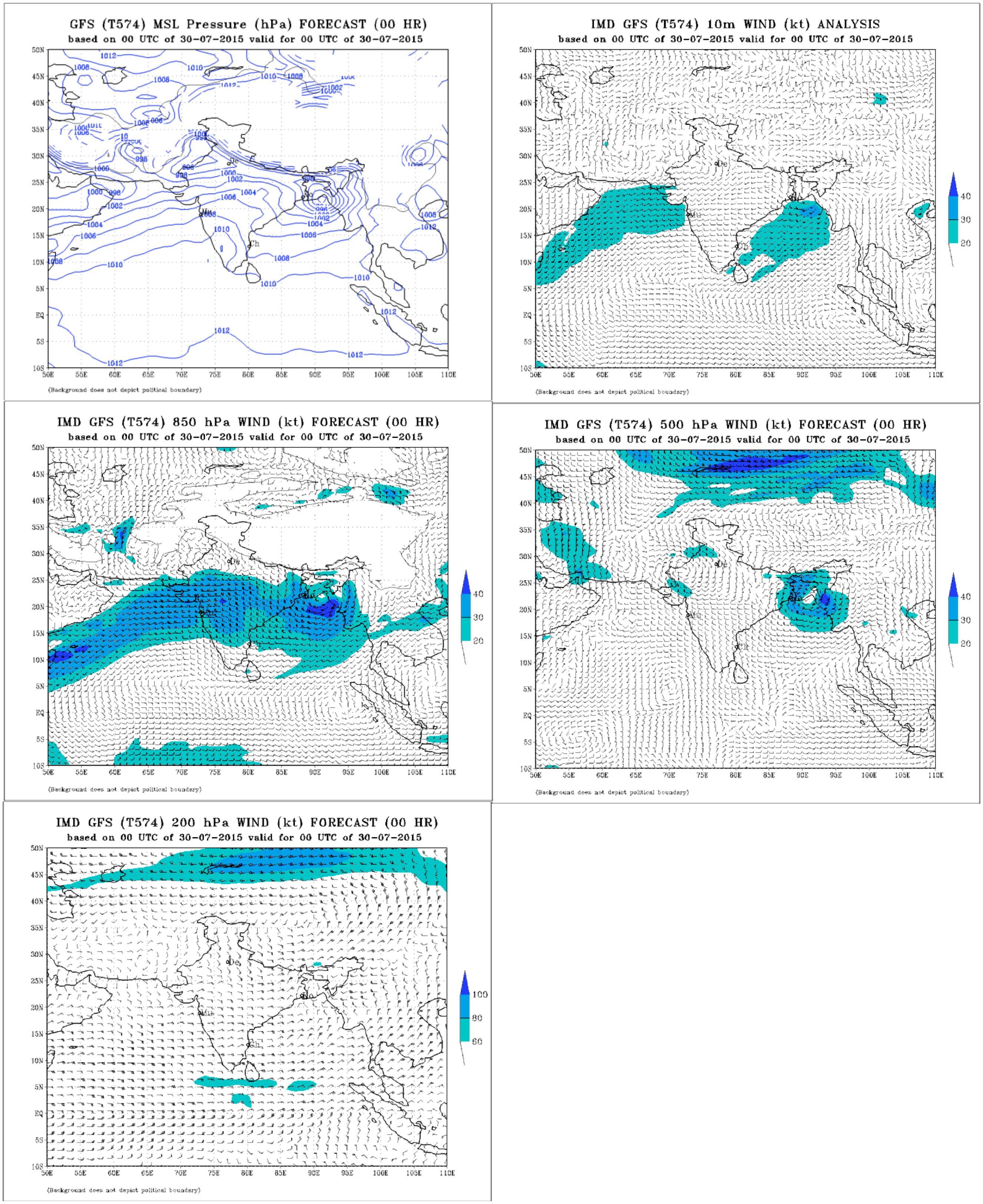


Fig2.2.7 (d)IMD-GFS analysis of (a) MSLP, (b) 10m wind, winds at (c) 850 hPa,(d) 500 hPa& (e) 200 hPa levels and based on 0000 UTC of 30th July, 2015

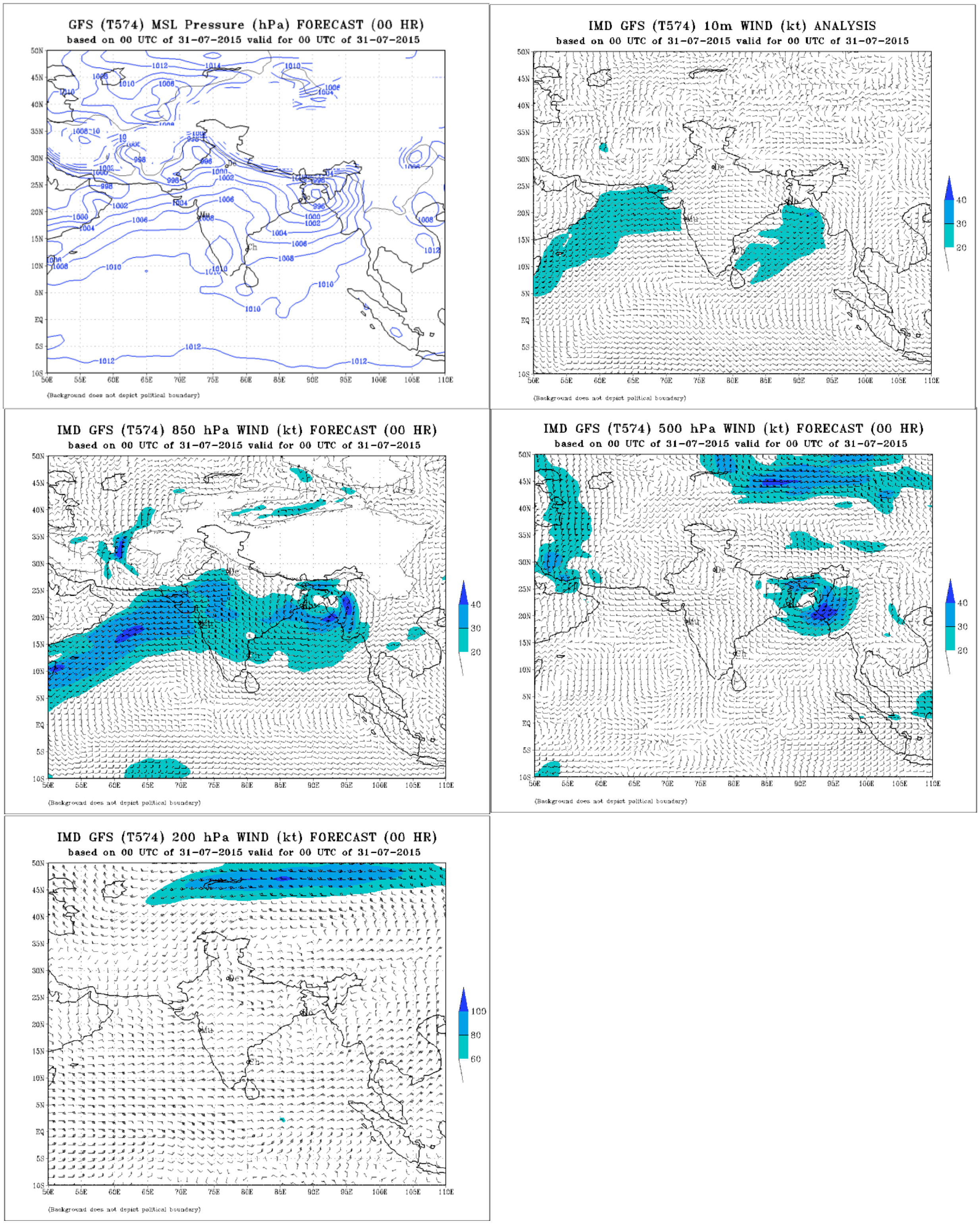


Fig2.2.7 (e)IMD-GFS analysis of (a) MSLP, (b) 10m wind, winds at (c) 850 hPa, (d) 500 hPa& 200 hPa levels and based on 0000 UTC of 31st July, 2015

2.2.8. Realized Weather:

2.2.8.1 Heavy rainfall due to KOMEN:

The CS Komen caused heavy to very heavy rainfall in Myanmar during 26-31 July and heavy rainfall in Bangladesh during 28 - 30 July 2015.

The Cyclonic storm also caused isolated heavy to very heavy rainfall over Odisha, Gangetic West Bengal, Jharkhand, Nagaland, Manipur, Mizoram, Tripura, Assam, Meghalaya, Arunachal Pradesh, East Madhya Pradesh and Chhattisgarh. The chief amounts of past 24 hr rainfall realised (≥ 7 cm) ending at 0300 UTC of date during the period of CS KOMEN are furnished below:

(Description of rainfall terminologies: Heavy: 64.5 to 124.4 mm; Very Heavy: 124.5 to 244.4 mm and Extremely Heavy: ≥244.5 mm) as well as spatial distribution [Isolated (ISOL): (1-25% of stations reporting rainfall); Scattered (SCT / A few places) : 26-50% of stations reporting rainfall; Fairly Widespread (FWS/ Many places): 51-75% of stations reporting rainfall; Widespread (WS/ Most places): 76-100% of stations reporting rainfall during the last 24 hours ending at 0300 UTC of every day).

26th July, 2015: (Rainfall in centimeter)

India

Nagaland, Manipur, Mizoram & Tripura: Bungtlang (ARG)-11, Chhuarllung (ARG)-9

Gangetic West Bengal: Dhaniakhali ARG-10, Canning-9, Uluberia, Kansabati Dam & Harinkhola-8 each and Bagati-7.

Odisha: Mandira Dam-9, Khandapara-9, Kuchinda-8 and Danagadi ARG & Panposh-7 each.

Bihar: Dehri-10.

Myanmar

Ann 21,Maungdaw 19, Sittwe & Myauk U 18 each, Kyauktaw 17, Paletwa 15, Kyaukpyu 14, Thandwe & Mawlamyine 12 each, Taungkok, Khayan & Kyeikkhame 11 each, Thaton, Myaungmya & Ngathyinechang 9 each, Pinlaung 8, Mudon, Shwegyin, Hakha, Nyaung Lay Bin & Phyarpon 7 each.

27th July 2015

India

Nagaland, Manipur, Mizoram & Tripura: Sabroom-9 And Bungtlang (ARG)-7

Gangetic West Bengal: Bankura (CWC)-14, Kansabati Dam, Phulberia & Bankura-10 each and Kharidwar-9.

Odisha: Lahunipara-17, Jamankira-15, Deogarh-12, Banaigarh AWS & Keiri AWS-11 each, Tensa & Rengali-10 each, Naktideul, Reamal, Chendipada, Barkote & Chandanpur-9 each, Batagaon, Karanjia, Kujanga ARG & Kaniha ARG-8 each and Marsaghai ARG, Swam-Patna, Joda ARG, Ghatagaon, Chandbali, Pallahara & Rairakhol-7 each.

Jharkhand: Nimdih & Chandil-8 each and Jamshedpur-7.

Myanmar

Myauk U 30, Sittwe & Kyauktaw 20 each, Maungdaw & Khayan 18 each, Gwa 16, Thandwe 15, Paletwa 14, Hakha 13, Launglon & Taungkok 10 each, Kyeikkhame & Kyopinkauk 9, Hpa-An, Yay, Kyaukpyu, Belin, Kalay & Gangaw 8 each and Phyu 7.

28th July, 2015:

India

Gangetic West Bengal: Purihansa-24, Tusuma-13, Purulia-12, Simula-11, Kharidwar-9 and Phulberia-7.

Odisha: Tiring-23, Rairangpur-21, Balikuda ARG-19, Tirtol ARG-18, Dhamnagar ARG, Paradeep CWR, Binjharpur ARG & Salepur ARG-17 each, Kujanga ARG, Marsaghai ARG & Korei ARG-16 each, Kendrapara, Raghunathpur ARG, Garadapur ARG, Jagatsinghpur AWS, Swam-Patna, Banki ARG, Pattamundai, Jajpur & Jenapur-15 each, Joshipur & Karanjia-14 Each, Nawana, Derabis ARG, Bonth & Chandanpur-13 each, Bari ARG, Mahanga ARG, Danagadi ARG & Daitari-12 each , Bhuban ARG & Anandpur-11 each, Thakurmunda-10, Alipingal, Tihidi ARG, Hindol, Kantapada ARG & Ghatagaon-9 each, Mandira Dam, Betanati ARG, Sukinda & Kakatpur-8 each and Kaniha ARG, Rajkanika & Bangiriposi-7 each.

Jharkhand: Jamshedpur AERO-20, Ghatsila-10, Putki & Topchanchi-9 each, Nimdih & Nandadih-8 each and Dumka & Dumri-7 each.

Bihar: Sheikhpura-9

Myanmar

Sittwe 13, Phyu 12, Taungkok 11, Thieinzayet & Thaton 10 each, Hmawbi, Kyopinkauk, Zaungtu, Mudon & Khayan 9 each.

Bangladesh

Noakhali 12, Barisal 10, Teknaf, Chandpur 7.

29th July, 2015:

India

Gangetic West Bengal: Uluberia-21, Tamluk (AWS)-19, Contai-14, Dhaniakhali (ARG)-11, Harinkhola-10, Labpur-9, Narayanpur & Sri Niketan-8 each.

Odisha: Chandanpur-16, Rairangpur & Bhograi-13 each, Bangiriposi-12, Nawana-10, Jaleswar-7.

Jharkhand: Ghatsila-15, Dhanbad-10, Sarath-8, Dumka-7.

Myanmar

Thieinzayet 22, Kyeikkhame & Paletwa 16 each, Thandwe 13, Hmawbi & Phyarpon 11 each, Kabaaye & Loikaw 10 each, Taungkok, Sittwe & Hakha 9 each, Kyaukpyu 8

Bangladesh

Barguna 11, Barisal 10, Teknaf 9, Patuakhali 7.

30th July, 2015:

India

Gangetic West Bengal: Manteswar-20, Harinkhola-19, Salar-11, Amtala, Dhaniakhali ARG & Burdwan (PTO)-9 each, Murarai, Contai, Narayanpur & Mangalkote-8 each and Durgachack-7.

Myanmar

Kyeikkhame 24, Hmawbi 23, Phyu 19, Paletwa, Thieinzayet 17, Kabaaye 15, Loikaw, Pinlaung 14, Phyarpon, Mindat 13, Kyopinkauk 12, Thandwe, Manaung, Myauk U 9, Taunggu(Aviation Met.), Thaton, Shwegyin 8 each, Mingalardon and Mudon 7 each.

Bangladesh

Teknaf 12, Khulna 11, Satkhira 8.

31st July, 2015:

India

Nagaland, Manipur, Mizoram & Tripura: Chhuarllung (ARG)-14, Bungtlang (ARG)-13.

Gangetic West Bengal: Digha & Hetampur-8 each.

Odisha: Bhograi-8.

Jharkhand: Maheshpur-17, Dumka & Jarmindi-15 each, Moharo & Sarath-9 each and Giridih, Topchanchi, Jamtara & Messenjore-7each.

Myanmar

Bago 23, Paletwa 22, Thieinzayet 21, Mindat 20, Kyeikkhame 18, Kabaaye 17, Loikaw 16, Khayan 14, Kyopinkauk, Myauk U, Manaung 11, Mudon 10, Katha 9, Launglon, Myaungmya, Heho 8.

01st August, 2015:

India

Assam & Meghalaya: Cherrapunji (RKM)-15, Cherrapunji-9 and Shillong C.S.O. & Shillong (AWS)-7 each.

Nagaland, Manipur, Mizoram & Tripura: Thoubal (AWS) & Imphal T AERO-9 each.

Gangetic West Bengal: Contai-16, Basirhat (PT)-15, Kolkata (Alipore) & Kolkata (Dum Dum)-13 each, Barrackpur (LAF) & Mohanpur-10 each, Burdwan (PTO), Midnapore (CWC), Midnapore & Canning-9 each, Durgapur & Phulberia-8 each and Hetampur, Dhaniakhali (ARG), Asansol (CWC), Kalyani SMO, Suri (CWC), Tusuma, Panagarh (LAF), Tilpara Barrage, Mangalkote, Mankar & Bankura (CWC)-7 each.

Jharkhand: Dumri-13, Hazaribagh-9, Panki, Kuru & Messenjore-8 each, Daltonganj & Sarath-7 each.

Bihar: Buxar-11, Indrapuri-10, Daudnagar-9, Jalalpur & Bodh Gaya-8 each, Hathwa & Dehri-7 each.

02nd August, 2015:

India

Gangetic West Bengal: Mangalkote-11, Narayanpur & Burdwan (PTO)-9 each, Mankar-8 and Sri Niketan, Murarai, Harinkhola & Bankura (CWC)-7 each.

Odisha: Khairamal-10, Jujumura ARG-8, Kantapada ARG-7.

Jharkhand: Deoghar, Putki and Koner-11 each, Ramgarh, Barkisuriya & Barhi-10 each, Mandar-9, Rajdhanwar, Jarmindi, Pathalgada, Dhanbad, Hindgir & Tenughat-8 each and Lohar-Daga, Moharo, Chatra, Bokaro, Giridih, Papunki, Hazaribagh, Jamtara, Sarath and Jaridih-7 each.

Bihar: Rajauli-8, Nawada -7.

03rd August, 2015:

India

Arunachal Pradesh: Wakra (ARG)-11, Tezu-9, Passighat-7

Odisha: Bargaon-23, Jharsuguda, Rajgangpur& Lakhanpur ARG-19 each, Deogaon, Mandira Dam & Sundargarh-17 each, Kirmira ARG & Ambabhona-16 Each, Laikera-14, Hemgiri-13, Panposh-12, Kolabira ARG-9, Atabira ARG & Balisankara ARG-8 each and Bonth-7.

Jharkhand: Raidih-14, Kurdege-12, Bagodar I-11, Kuru, Hazaribagh & Simdega-10 Each, Daltonganj-8 and Palkot, Lohar-Daga, Torpa & Latehar-7 each.

East Madhya Pradesh: Mandla-AWS-13, Nagode-7.
Chhattisgarh: Raigarh-22, Gharghoda-10, Saraipali-7.

04th August, 2015:

India

East Madhya Pradesh: Amarwara & Balaghat-AWS-15 each, Narsinghpur-AWS-13, Seoni-AWS, Gotegaon & Chindwara-AWS-12 Each, Keolari & Katangi-11 each, Lakhnadon-10, Jabalpur-New—AWS, Gadarwara & Kareli-9 each, Malanjkhand & Deori-8 each and Dindori-AWS-7.

Chhattisgarh: Bemetara-12, Korba-10, Katghora-9, Pali-8, Raigarh-7

(AWS: Automatic Weather Station; ARG: Automatic Raingauge Station; CWC: Central Water Commission; IAF: Indian Air Force)

Rainfall associated with the cyclone when it was out in the sea is also determined based on satellite-gauge merged rainfall dataset generated by IMD and NCMRWF (Mitra et al, 2009) for the North Indian Ocean region from 2013 onwards using the TRMM data. 24-hour accumulated rainfall associated with the CS KOMEN during the period 26 July-04 August as well as the 7-day average rainfall during the same period is furnished in the Fig.2.2.8.

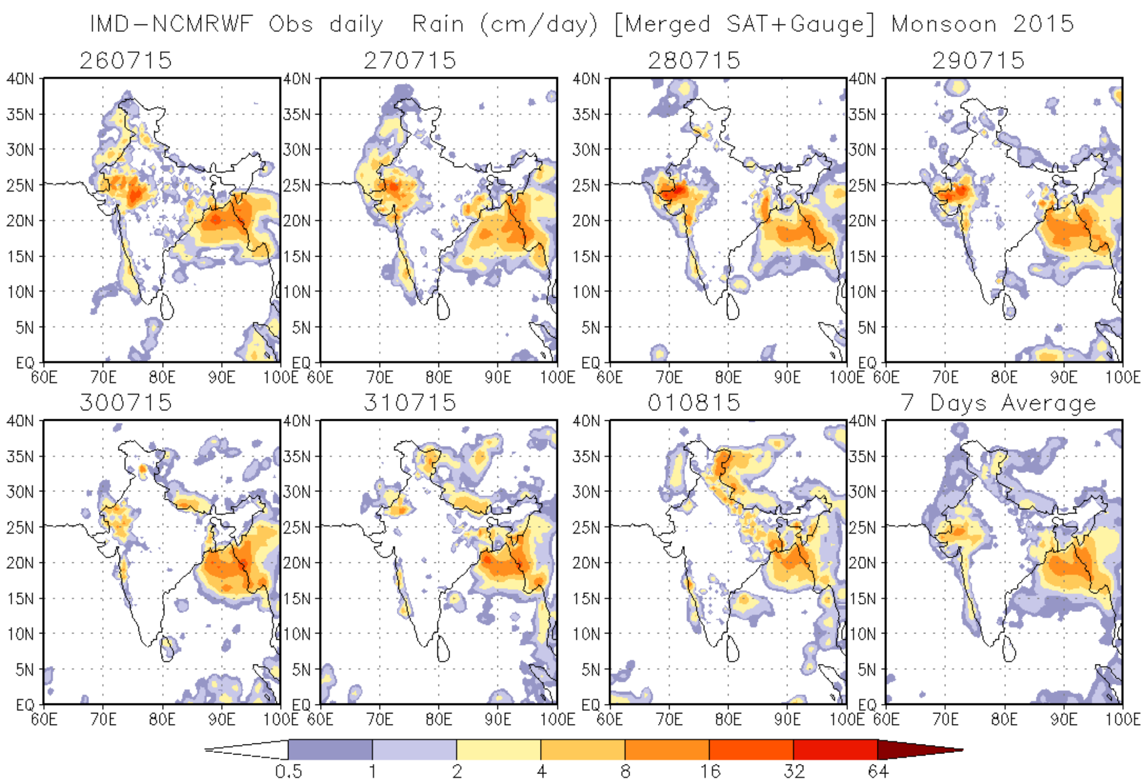


Fig.2.2.8 IMD-NCMRWF (TRMM based) daily merged rainfall during 26 July to 01 Aug

From the figures it is observed that the maximum rainfall occured in the southeastern sector of the system centre when the system was in the sea i.e. during the period 26-30 July. After landfall, the maximum rainfall belt gradually shifted to southwest sector. This shift in the maximum rainfall regime is associated with gradual recurvature of the TC from northward movement over the sea to northwestward and west-northwestward movement after landfall. This spatial pattern of rainfall distribution was in expected lines as it has occurred in a similar fashion in earlier cases also.

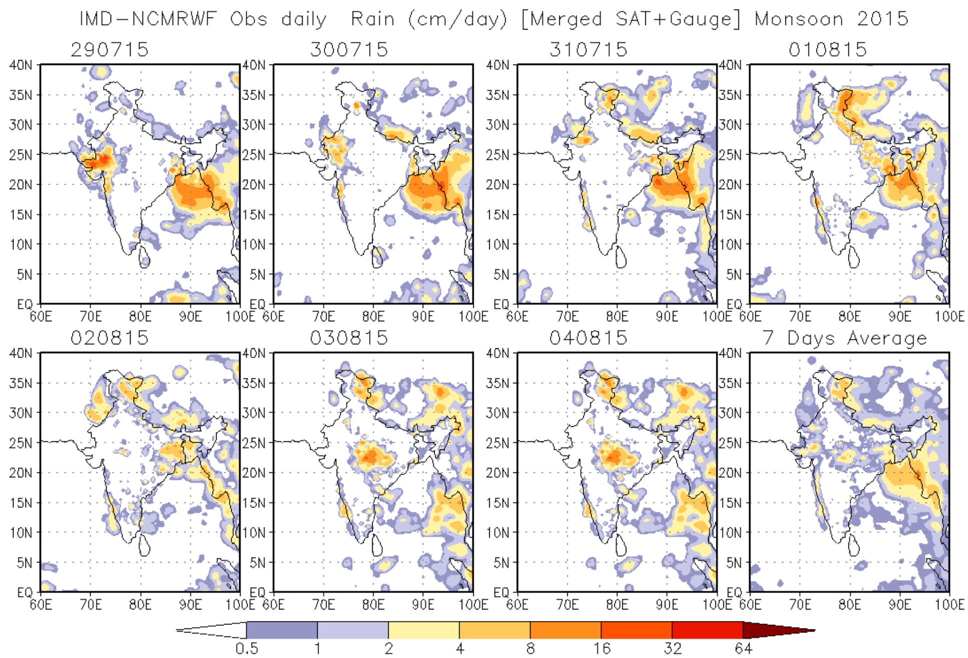


Fig.2.2.8 (contd.) IMD-NCMRWF (TRMM based) daily merged rainfall during 29 July to 04 Aug 2015 and 07-day average rain during the above periods.

2.2.8.2 Gale Wind

Maximum gale wind of 100 kmph prevailed over Teknaf (Bangladesh) on 29th July night when the CS was lying over northeast BoB close to southeastern coast of Bangladesh. However, the wind speed at the time of landfall was about 60-70 kmph along Bangladesh coast.

2.2.8.3 Storm Surge

RSMC New Delhi predicted that tidal wave (storm surge + astronomical tide) of about 2 meters would inundate low lying areas of Bangladesh coast around the time of landfall as the coastal inundation model of Bangladesh did not predict any significant storm surge and the tidal wave was expected to be about 2 meters.

2.2.9. Damage due to Cyclone 'KOMEN'

Damage in West Bengal

The details of the damages in West Bengal due to KOMEN are given below in Table 2.2.2.

Table -2.2.2 Damages associated with CS KOMEN

S No.	Specification	
1	Districts Affected	12
2	Block Affected (Nos.)	233
3	Municipality	53
4	Corporation	2

5	Gram Panchayat	781
6	Village Affected(Nos.)	16,309
7	People affected	61,29,965
8	Loss of human Loss	83
9	Loss of livestock	10,088
10.	Housing	
11	Number of Affected houses (no.)	41269
	(i) completely damaged	1,07,808
	(ii) partially damaged	3,68,238

Damage in Odisha

No damage was reported in Odisha.

Damage in Bangladesh

According to press and media reports, rain/floods and lightning claimed 6 lives in Bangladesh and about 88900 houses were damaged partially.

Damage in Myanmar

According to press and media reports, 2 persons died and 2 were injured. 86 houses and 4 primary schools were damaged

2.3 Extremely Severe Cyclonic Storm (ESCS) Chapala over the Arabian Sea (28 October - 04 November 2015)

2.3.1 Introduction

An Extremely Severe Cyclonic Storm 'Chapala' formed from a low pressure area over southeast Arabian Sea which concentrated into a depression in the morning of 28th October. It moved north-northwestwards and intensified into a deep depression in the same evening. It further intensified into a cyclonic storm in the early hours of 29th over eastcentral Arabian Sea. It then moved west-northwestwards, further intensified into a severe cyclonic storm in the evening and a very severe cyclonic storm in the midnight of 29th and into an extremely severe cyclonic storm in the morning of 30th. It then moved mainly westwards, maintained its intensity till 1st November and then started weakening gradually. Moving west-northwestwards, it crossed Yemen coast to the southwest of Riyan (14.1^{0}N/48.65^{0}E) during 0100-0200 UTC of 3rd November as very severe cyclonic storm. It further westwards and weakened into a severe cyclonic storm in the morning, into a cyclonic storm by noon and into deep depression around midnight of 3rd November. it then weakened into a depression in the early morning of 4th and lay as well marked low pressure area over Yemen at 0300 UTC of 4th November. The salient features of this cyclone are as follows.

i. ESCS Chapala is the first severe cyclone to cross Yemen coast after the severe cyclonic storm of May 1960.
ii. The ESCS Chapala had a life period of 7 days , which is above normal (average life period of VSCS/ESCS is 6 days in NIO and 4.7 days in Post monsoon season for VSCS/ESCS)

iii. It had the maximum intensity of 115 kts (215 kmph) and crossed Yemen coast with a speed of 65 knots (120 kmph).

iv. The system had the longest track length after VSCS Phet in 2010. It travelled a distance of about 2248 km during its life period.

v. The Accumulated Cyclone Energy (ACE) was about 18.29 X 10^4 $knot^2$ (the mean for the period (1990-2013) in the post monsoon season over Arabian Sea is 0.8 X 10^4 $knot^2$), which is same as VSCS, Phet over Arabian Sea in 2010.

vi. The Power Dissipation Index was 17.92 X 10^6 $knot^3$ which is also same as that of VSCS Phet in 2010 (the mean for the period (1990-2013) in the post monsoon season is 0.4 X 10^6 $knot^3$.

vii. The system rapidly intensified from 29th morning to 30th afternoon, when the speed increased from 35 kts at 0000 UTC of 29th Oct to 90 kts at 0900 UTC of 30th Oct.

viii. Though the system moved over to colder Gulf of Aden, experienced dry air intrusion and interacted with the land surface, it did not weaken rapidly due to low vertical wind shear around the centre and in the forward sector of the system.

ix. There was large divergence and hence higher than normal errors in NWP models for prediction of its track and intensity especially, the landfall over Yemen.

x. RSMC New Delhi predicted genesis on 25th October, 3 days in advance and its intensification to ESCS one day in advance on 29th October 2015. The forecast of landfall over Yemen and adjoining Oman coast was issued on the day of genesis i.e., 28th Oct., 6 days advance and landfall over Yemen was issued on 31 Oct. with a lead period of 5 days. Every 3 hourly Tropical Cyclone Advisories were issued to WMO/ESCAP panel countries including Oman and Yemen & Somalia.

Brief life history, characteristic features and associated weather along with performance of numerical weather prediction models and operational forecasts of IMD are presented and discussed in following sections.

2.3.2 Monitoring of ESCS, Chapala

The ESCS Chapala was monitored & predicted continuously since its inception by the India Meteorological Department (IMD). The forecast of its genesis (formation of Depression) on 28th October, its track, intensity, point & time of landfall was well predicted by IMD. The system was monitored mainly by observations from satellite throughout its life period. Various national and international NWP models and dynamical-statistical models including IMD and National Centre for Medium Range Weather Forecasting (NCMRWF) global and meso-scale models, dynamical statistical models for genesis and intensity were utilized to predict the genesis, track and intensity of the storm. Tropical Cyclone Module, the digitized forecasting system of IMD was utilized for analysis and comparison of various models guidance, decision making process and warning product generation.

2.3.3 Brief life history

2.3.3.1 Genesis

During the onset phase of northeast monsoon, a trough of low with embedded upper air cyclonic circulation in lower levels lay over southeast Bay of Bengal on 25th Oct. Under its influence, a low pressure area formed over southeast and adjoining southwest and eastcentral Arabian Sea at 0300 UTC of 26th Nov. with associated cyclonic circulation extending upto mid-tropospheric levels. It became well marked over the same region at

0300 UTC of 27th morning. It concentrated into a depression over southeast and adjoining southwest and central Arabian Sea at 0300 UTC of 28th October near Lat. 11.5°N and Long. 65.0° E.

The winds were stronger in northern sector (25-30 knots) under the influence of northeast monsoon current and were about 15-20 knots in other sectors as seen from multi-satellite surface winds. The Sea Surface Temperature (SST) was about 30°C around the region of depression. The vertical wind shear was moderate (10-20 knots) around the system centre and was low (5-10 knots) to the west-northwest of the system centre. The low level relative vorticity was about 100 x 10^{-5} $second^{-1}$ and low level convergence was 5-10 x 10^{-5} $second^{-1}$. The upper level divergence was 30 x 10^{-5} $second^{-1}$. The ocean thermal energy was about 60-80kJ/cm^2. MJO lay in phase 2 (west equatorial region) with amplitude greater than 2.

2.3.3.2 Track and intensification

Best track parameters of ESCS, Chapala over AS (28^{th} Oct.-4^{nd} Nov., 2015) are given in Table 2.3.1. The observed track of the system is also shown in Fig. 2.1.

The environmental features and large scale features as mentioned in the previous section continuously favoured the intensification of the system during 28^{th} -30 Oct. The system rapidly intensified from 29th to 30th, when the speed increased from 35 kts at 0000 UTC of 29th Oct to 90 kts at 0900 UTC of 30th Oct. There was land interaction and impact of dry air intrusion from northwest from 01 Nov. onwards. However, the impact of dry air intrusion from northwest and land interaction was slow because of low vertical wind shear to the west and west-southwest of the system as can be seen in Fig. 2.10.1 and hence the system could maintain its intensity of ESCS from 0000 UTC of 30th Oct. to 0900 UTC of 2 Nov. The Total Precipitable Water (TPW) imageries during 28 Oct. to 04 Nov. is shown in Fig. 2.10.3 which clearly exemplifies the low impact of dry air intrusion into the wall cloud region. From 0300 UTC of 2^{nd} Nov. The system started interacting with land surface and also the convection in the wall cloud region showed signs of disorganisation indicating the weakening trend of the system. It crossed Yemen coast to the southwest of Riyan (14.1^0N/48.65^0E)during 0100-0200 UTC of 3^{rd} November as Very Severe Cyclonic Storm (VSCS). It then weakened rapidly into SCS at 0300 UTC, into a CS at 0600 UTC and into a Deep Depression (DD) at 1800 UTC on the same day due to land interaction. It further weakened into a Depression at 0000 UTC and into a well marked low pressure area at 0300 UTC of 4^{th} November 2015 over Yemen.

The system initially moved north-northwestwards in association with the anti-cyclonic circulation lying to the northeast of the system centre. It then came under the influence of another anti-cyclonic circulation to its northwest on 29th which increased westward component in the movement of the system. The system lay in the south eastern periphery of this anticyclone. Thus the system moved nearly westwards to west-southwestward upto 0300 UTC of 2 Nov. It then lay to the southwest of the anticyclone and the ridge (Lat. 16°N) at 200 hPa and thus moved west-northwestwards towards Yemen coast. It moved normally with a speed of 13 kmph initially, its speed gradually picked up and became about 20 kmph on the day before landfall. The direction and translational speed of movement of the system is illustrated in Fig. 2.10.2

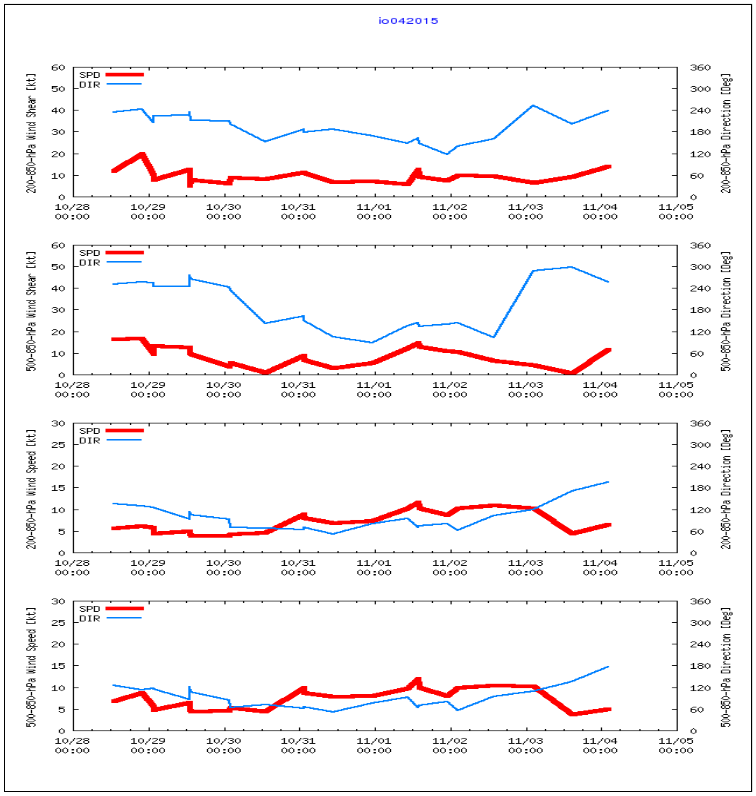


Fig.2.3.1 Wind shear and wind speed in the middle and deep layer around the system during 28th Oct. to 05th Nov 2015.

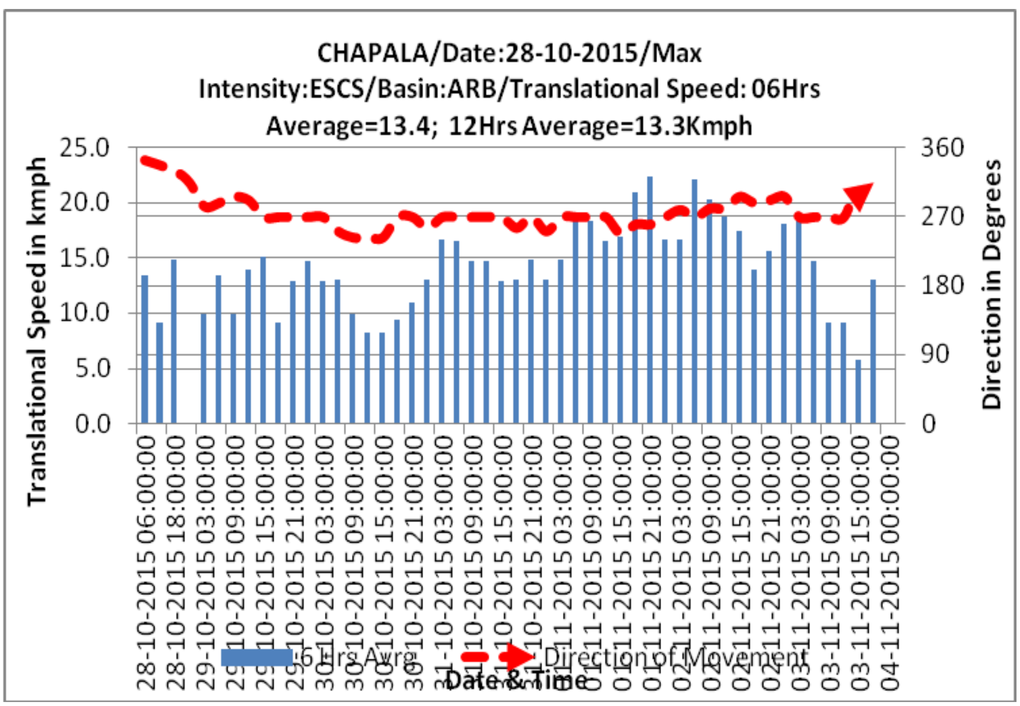


Fig. 2.3.2. Translational speed and direction of ESCS Chapala during 28th Oct. - 04th Nov 2015.

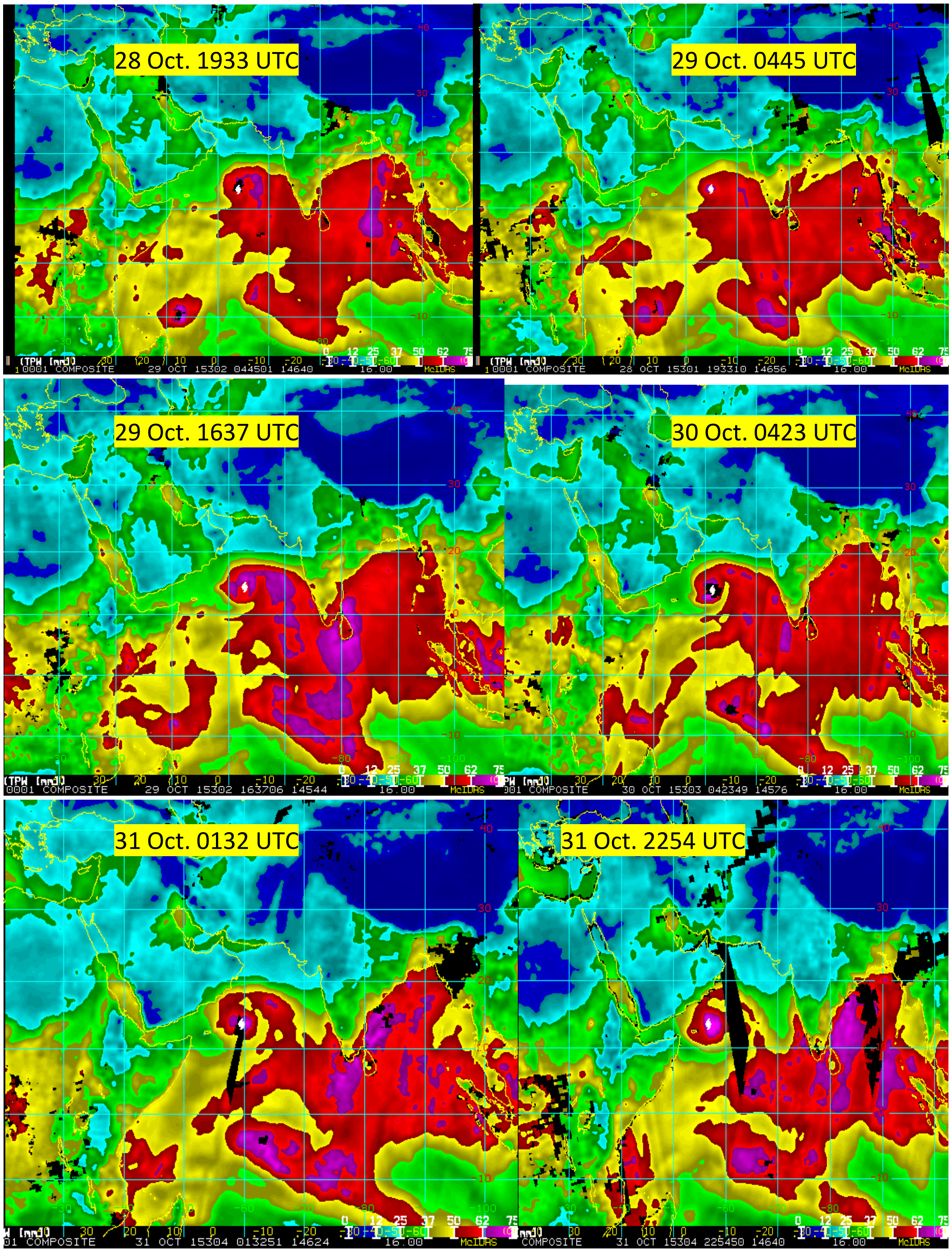


Fig. 2.3.3 TPW imageries of ESCS Chapala during 28th Oct. to 04th Nov 2015.

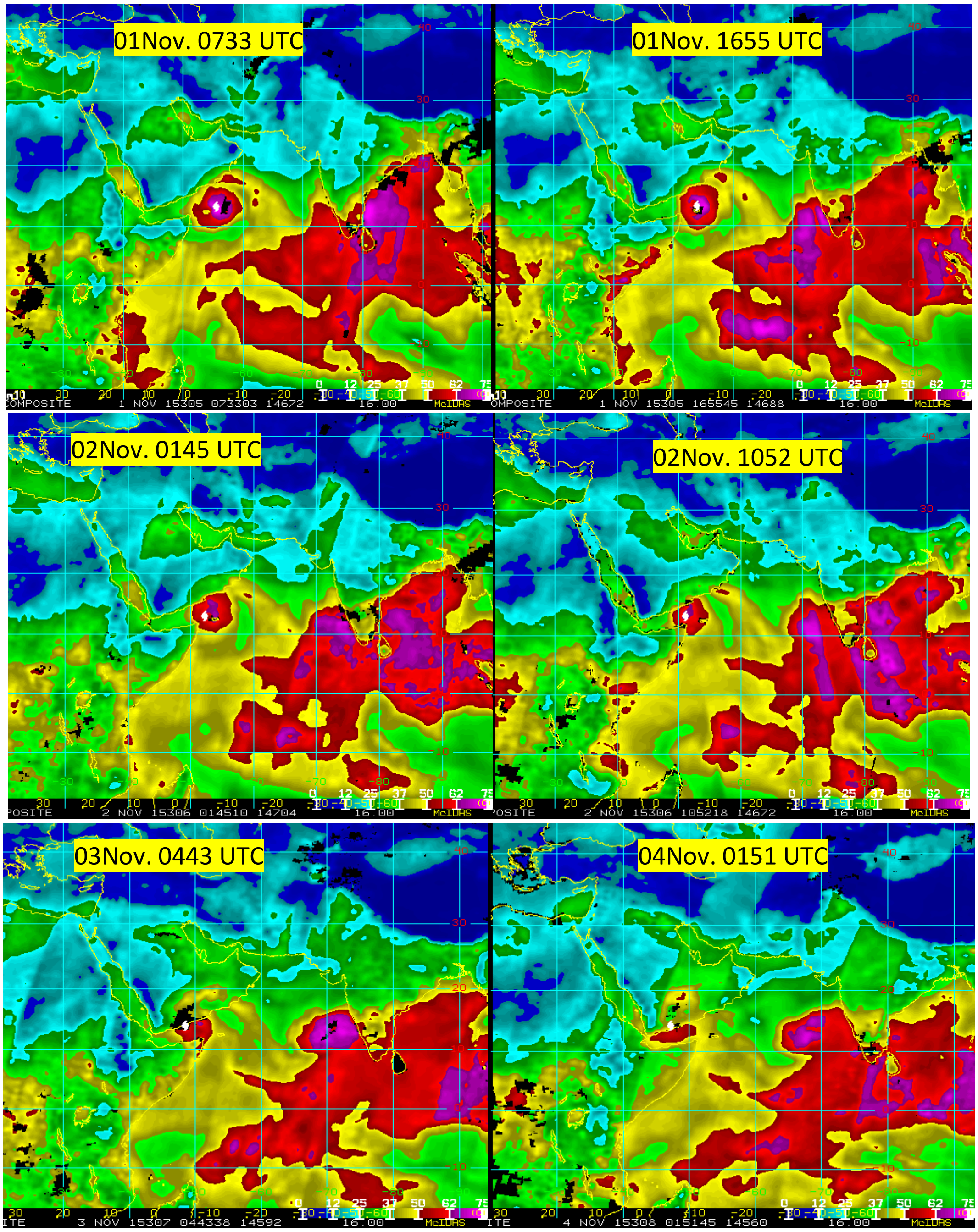


Fig. 2.3.3 contd. TPW imageries of ESCS Chapala during 28th Oct. to 04th Nov 2015.

Table 2.3.1 Best track positions and other parameters of ESCS CHAPALA over the Arabian Sea during 28 October-04 November, 2015

Date	Time (UTC)	Centre lat.° N/ long. ° E	C.I. NO.	Estimated Central Pressure (hPa)	Estimated Maximum Sustained Surface Wind (kt)	Estimated Pressure drop at the Centre (hPa)	Grade
28/10/2015	0300	11.5/65.0	1.5	1005	25	3	**D**
	0600	11.8/64.9	2.0	1004	25	4	D
	1200	12.5/64.7	2.0	1001	30	5	**DD**
	1800	13.0/64.7	2.0	1001	30	5	DD
29/10/2015	0000	13.7/64.3	2.5	999	35	7	**CS**
	0300	13.8/64.2	2.5	997	40	9	CS
	0600	13.9/63.8	3.0	996	45	10	CS
	0900	14.0/63.5	3.0	994	50	12	**SCS**
	1200	14.1/63.3	3.5	990	55	16	SCS
	1500	14.3/62.8	3.5	988	60	18	SCS
	1800	14.3/62.5	4.0	984	65	22	**VSCS**
	2100	14.3/62.3	4.5	976	75	30	VSCS
30/10/2015	0000	14.3/61.8	5.0	966	90	40	**ESCS**
	0300	14.3/61.5	5.5	954	105	52	ESCS
	0600	14.3/61.1	5.5	948	110	58	ESCS
30/10/2015	0900	14.2/60.8	6.0	940	115	66	ESCS
	1200	14.1/60.6	6.0	940	115	66	ESCS
	1500	14.0/60.4	6.0	940	115	66	ESCS
	1800	13.9/60.2	6.0	940	115	66	ESCS
	2100	13.9/59.9	6.0	942	115	64	ESCS
31/10/2015	0000	13.9/59.6	5.5	944	110	62	ESCS
	0300	13.8/59.2	5.5	946	110	60	ESCS
	0600	13.8/58.7	5.5	950	105	56	ESCS
	0900	13.8/58.3	5.5	950	105	56	ESCS
	1200	13.8/57.9	5.5	950	105	56	ESCS
	1500	13.8/57.5	5.5	950	105	56	ESCS
	1800	13.8/57.2	5.5	950	105	56	ESCS
	2100	13.7/56.8	5.5	950	105	56	ESCS
01/11/2015	0000	13.7/56.4	5.5	950	105	56	ESCS
	0300	13.6/56.1	5.5	952	105	54	ESCS
	0600	13.6/55.6	5.5	954	100	52	ESCS
	0900	13.6/55.1	5.5	956	100	50	ESCS

	1200	13.6/54.6	5.5	956	100	50	ESCS
	1500	13.6/54.2	5.5	956	100	50	ESCS
	1800	13.4/53.7	5.5	956	100	50	ESCS
	2100	13.3/53.1	5.5	956	100	50	ESCS
02/11/2015	0000	13.2/52.5	5.5	958	100	48	ESCS
	0300	13.2/52.2	5.0	960	95	46	ESCS
	0600	13.3/51.6	5.0	964	90	42	ESCS
	0900	13.3/51.0	5.0	966	90	40	ESCS
	1200	13.4/50.5	4.5	968	85	38	**VSCS**
	1500	13.5/50.0	4.5	970	85	36	VSCS
	1800	13.7/49.6	4.5	974	80	32	VSCS
	2100	13.8/49.3	4.0	978	75	28	VSCS
3/11/2015	0000	14.0/48.8	4.0	984	65	22	VSCS
	Crossed Yemen coast to the southwest of Riyan (14.1/48.65) during 0100-0200 UTC.						
	0300	14.2/48.4	-	990	55	16	**SCS**
	0600	14.2/47.8	-	996	45	10	**CS**
	0900	14.2/47.6	-	998	40	8	CS
	1200	14.2/47.3	-	998	40	8	CS
	1500	14.2/47.1	-	998	40	8	CS
	1800	14.3/47.0	-	1001	30	5	**DD**
04/11/2015	0000	14.8/46.5	-	1003	25	3	**D**
	0300	Well marked low pressure area over Yemen.					

2.3.3.3 Maximum Sustained Surface Wind speed and estimated central pressure:

The lowest estimated central pressure has been 940 hPa. The estimated maximum sustained surface winds (MSW) was 115 knots during 0900 - 2100 UTC of 30th Oct. However, at the time of landfall, the ECP was 984 hPa and MSW was 65 knots (very severe cyclonic storm) due to weakening of the system over Gulf of Aden. It can be seen from Fig.2.3.4 that there was rapid intensification from 29/0000 UTC to 30/0900 UTC.

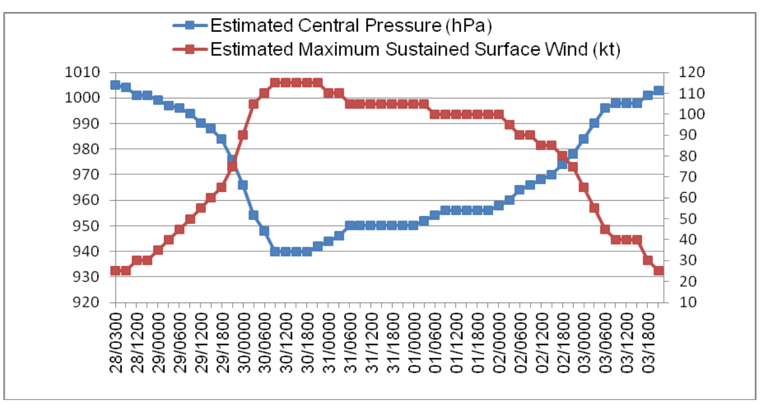


Fig. 2.3.4 Estimated Central Pressure (ECP) and estimated maximum sustained surface wind speed during 28th Oct./0300 UTC to 04th Nov/0000 UTC.

2.3.4 Climatological aspects

Climatologically, the severe cyclonic storms crossing Yemen coasts are very rare. Prior to Chapala, only one SCS in May 1960 crossed Yemen coast during the 1891-2014). The track of the SCS is shown in Fig.2.3.5.

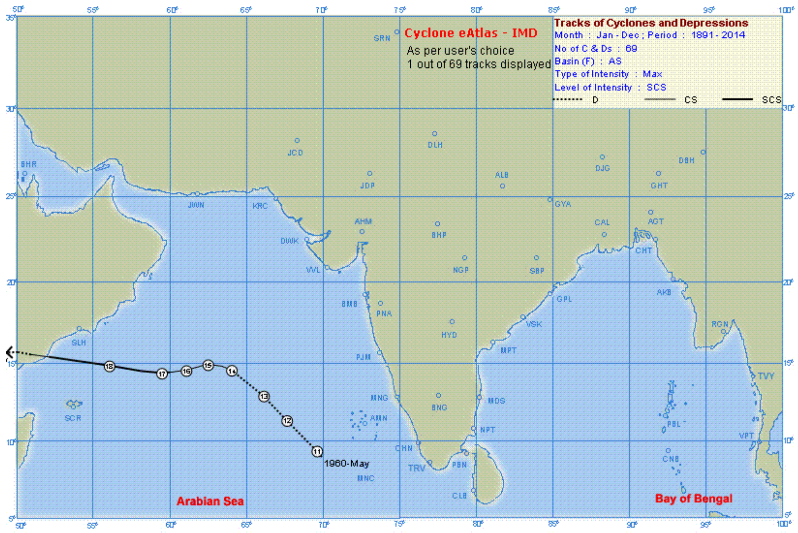


Fig. 2.3.5 Tracks of Severe cyclonic storm over Arabian Sea during the period 1891-2014 that crossed Yemen coast.

2.3.5 Features observed through satellite

(a) INSAT 3D and Kalpana imageries:

Half hourly Kalpana-1 and INSAT-3D imageries were utilised for monitoring of ESCS, Chapala. Satellite imageries of international geostationary satellites Meteosat-7 and MTSAT and microwave & high resolution images of polar orbiting satellites DMSP, NOAA series, TRMM, Metops were also considered. Typical satellite INSAT-3D imageries (IR, visible, IRBD and enhanced colour imageries) of ESCS Chapala representing the life cycle of the cyclone are shown in Fig2.3.6 to 2.3.9

As per the satellite imageries, on 26th October, broken low and medium clouds with embedded intense to very intense convection lay over south Arabian Sea between equator to latitude 10.0°N and longitude 61.0°E to 74.0°E in association with the low pressure area over the area.

On 27th/0300, vortex was observed over south Arabian Sea centered within half a degree of latitude 8.5°N and longitude 66.0°E with intensity T1.0 and poorly defined centre. Associated broken low and medium clouds with embedded moderate to intense convection lay over the area between latitude 6.0°N to 14.5°N and longitude 60.0°E to 72.0°E. The lowest cloud top temperature (CTT) associated with the vortex was -70°C. On 28th/0300 UTC, intensity of the system was T1.5 with convective clouds showing shear pattern and increase in organisation. On 28th/1200 UTC, the intensity of the system became T2.0 with increased convection and organisation into curved band pattern during the past 12 hours.

On 29th, the intensity of the system increased rapidly by three T numbers in 24 hrs. At29/0000 UTC, the intensity of the system was T.2.5. At 29/0300 UTC, it became T3.0, at 1200 UTC,T3.5 and at 1800 UTC of the same day, it was T4.0 and eye started appearing. On 30th/0000 UTC, intensity further increased to T5.5 with convective cloud showing eye pattern with well-defined eye of diameter about 15 km in both visible and IR imageries. By

0900 UTC of 30th, intensity further increased to T6.0 with well-defined eye of diameter about 15 km. At 2100 UTC of the same day, the eye pattern became ragged. By 31st/0000 UTC, intensity became T5.5 / CI 6.0 and the eye was ragged. At 0600 UTC of the same day, intensity became T5.0 / CI 6.0. However, ragged eye was observed in both visible and IR imageries. Minimum wall cloud temperature was -80°C. By 0900 of the same day, weakening trend was observed in the associated convection. At 1200 UTC of 31st, eye was defined in visible and IR imageries. At 1800 UTC of the same day, minimum wall cloud temperature was -77°C. There was a good poleward outflow from 0000 UTC of 29th Oct. which changed to radial outflow from 0000 UTC of 31st Oct. The poleward outflow again was seen from 1200 UTC of 01st Nov. to 0000 UTC of 2nd Nov.

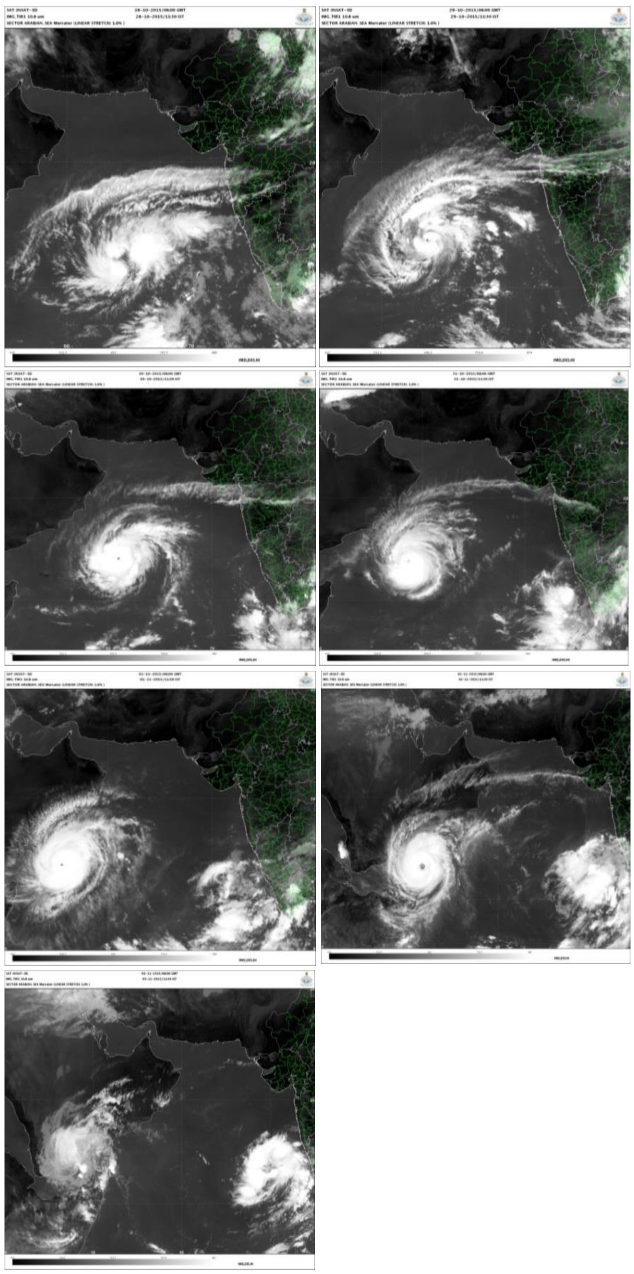


Fig. 2.3.6 INSAT 3D IR Imageries during 28 Oct.-3 Nov. 2015 basedon 0600 UTC.

On 01st November/0300 UTC, ragged eye re-appeared and the minimum wall cloud temperature was -90°C. At 0300 UTC of the same day, intensity slightly decreased to T5.5/ CI 5.5 and convection showed ragged eye pattern. On 2nd/0000 UTC, the eye diameter increased to about 45 km. At 0300 UTC of the same day, intensity decreased to T5.0/ CI 5.5 and convection in the wall cloud region started showing disorganisation. At 1200 UTC of the same day, intensity further decreased to T4.5/ CI 5.5. However, well defined ragged eye was observed in both visible and IR imageries. At 2100 UTC, the intensity further decreased to T4.0 / CI 4.5 and on 03rd/0000 UTC, convection was sheared to the northwest due to increase in vertical wind shear and further disorganisation continued till day of landfall.

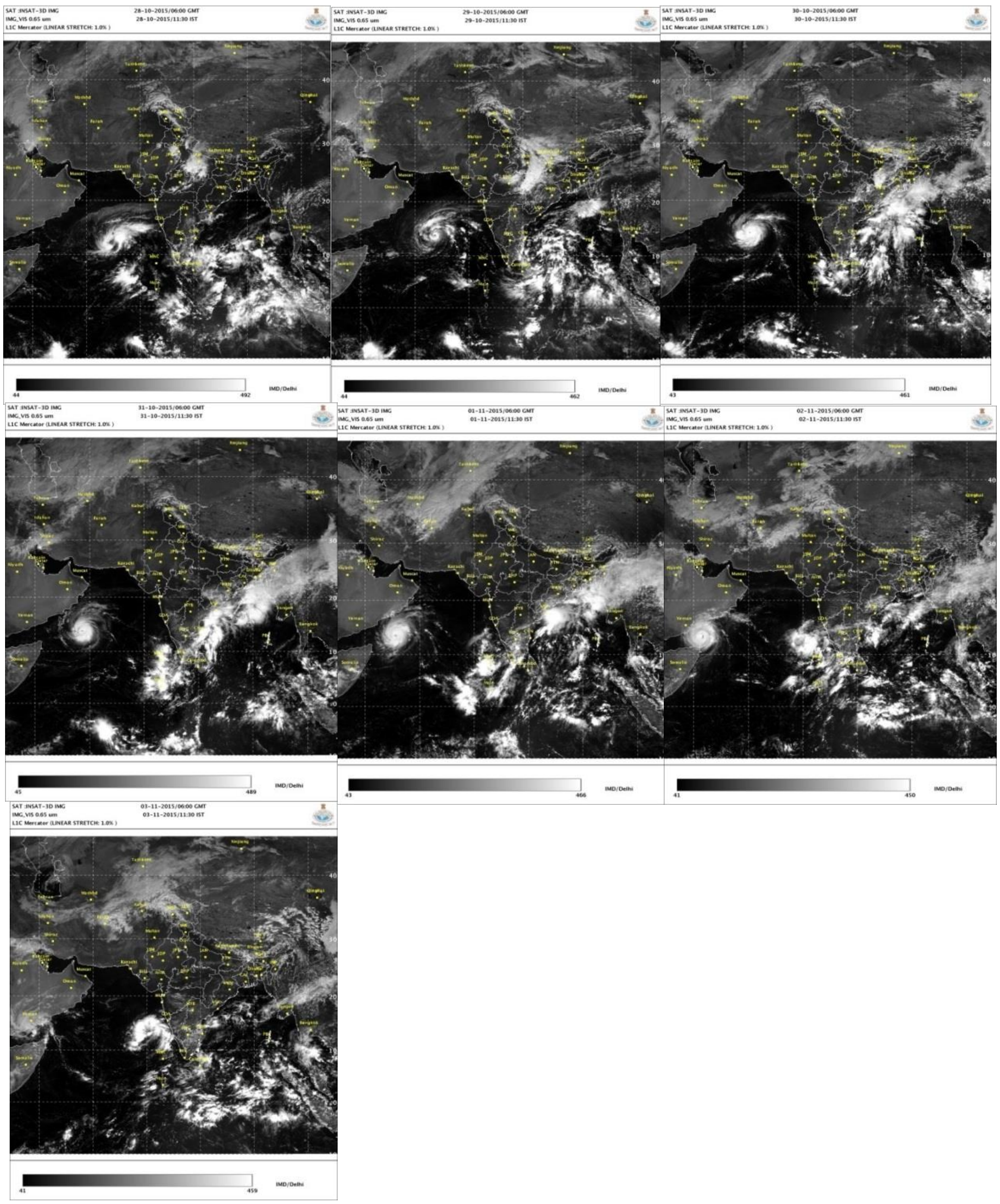


Fig. 2.3.7 INSAT 3D Visible Imageries during 28 Oct.-3 Nov. 2015 based on 0600 UTC.

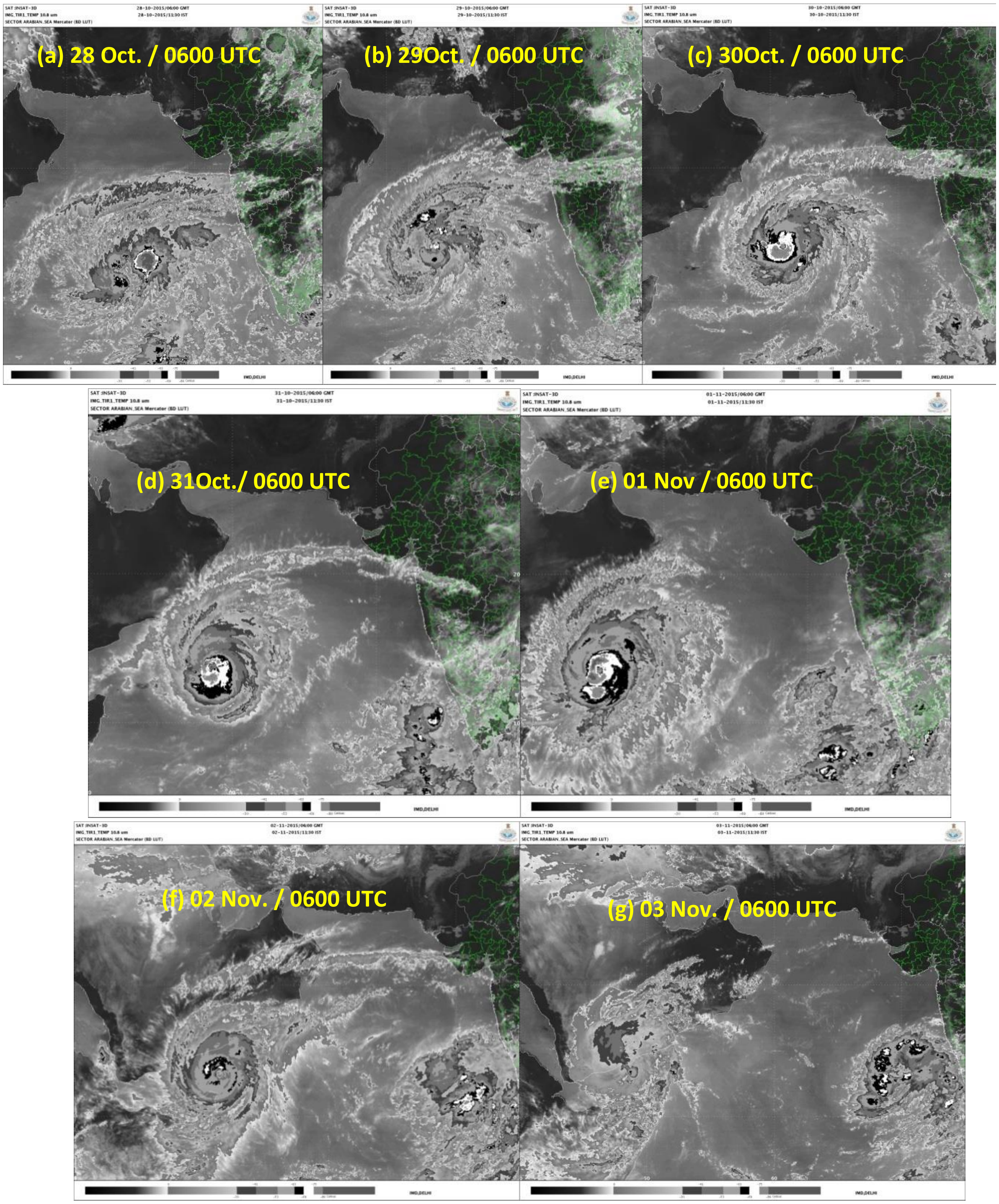


Fig. 2.3.8 (a-e) INSAT 3D Imageries during 28 Oct. - 4 Nov. 2015 based on 0600 UTC.

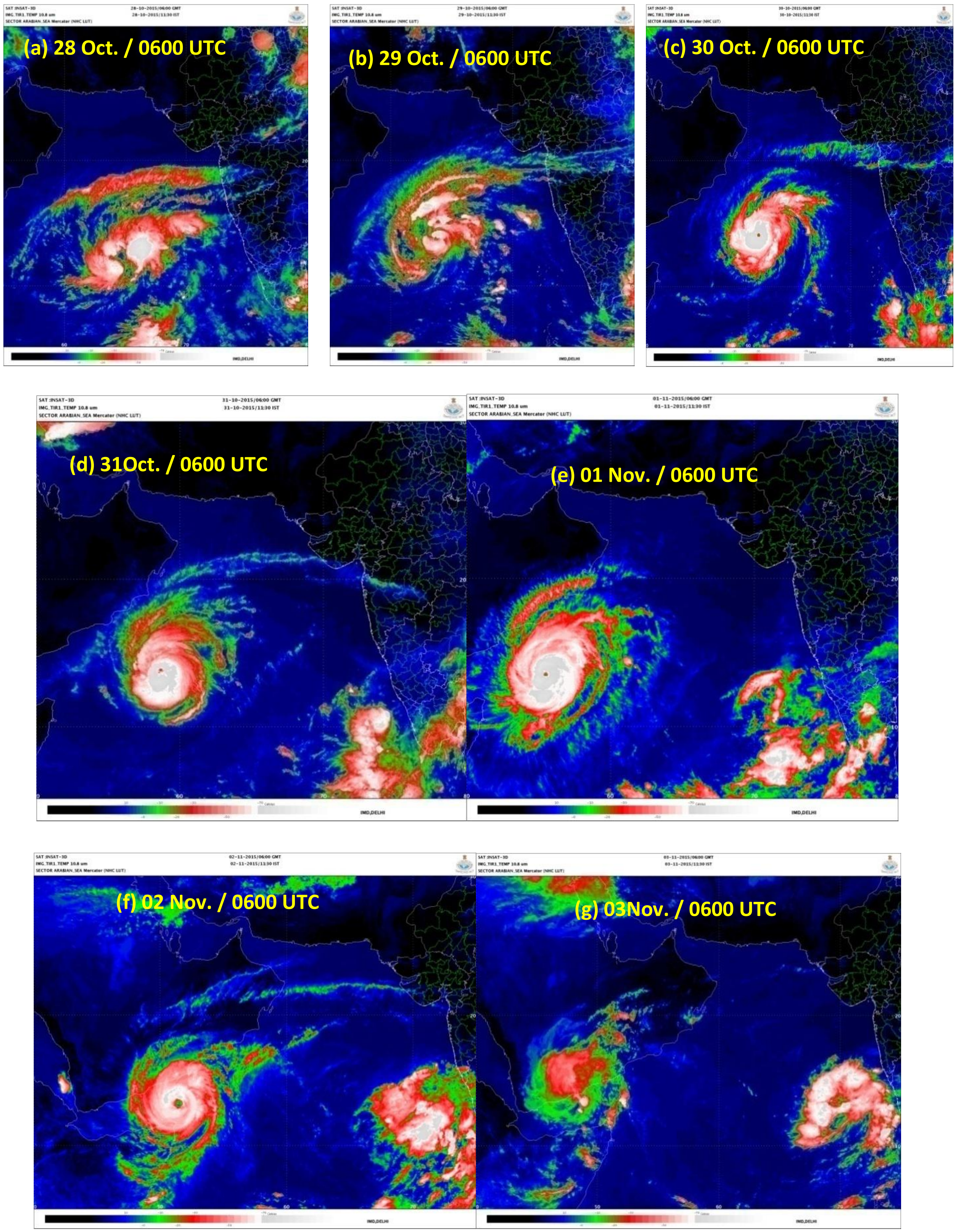


Fig. 2.3.9 (a-g) INSAT 3D enhanced imageries during 28 Oct. - 3 Nov. 2015 based on 0600 UTC.

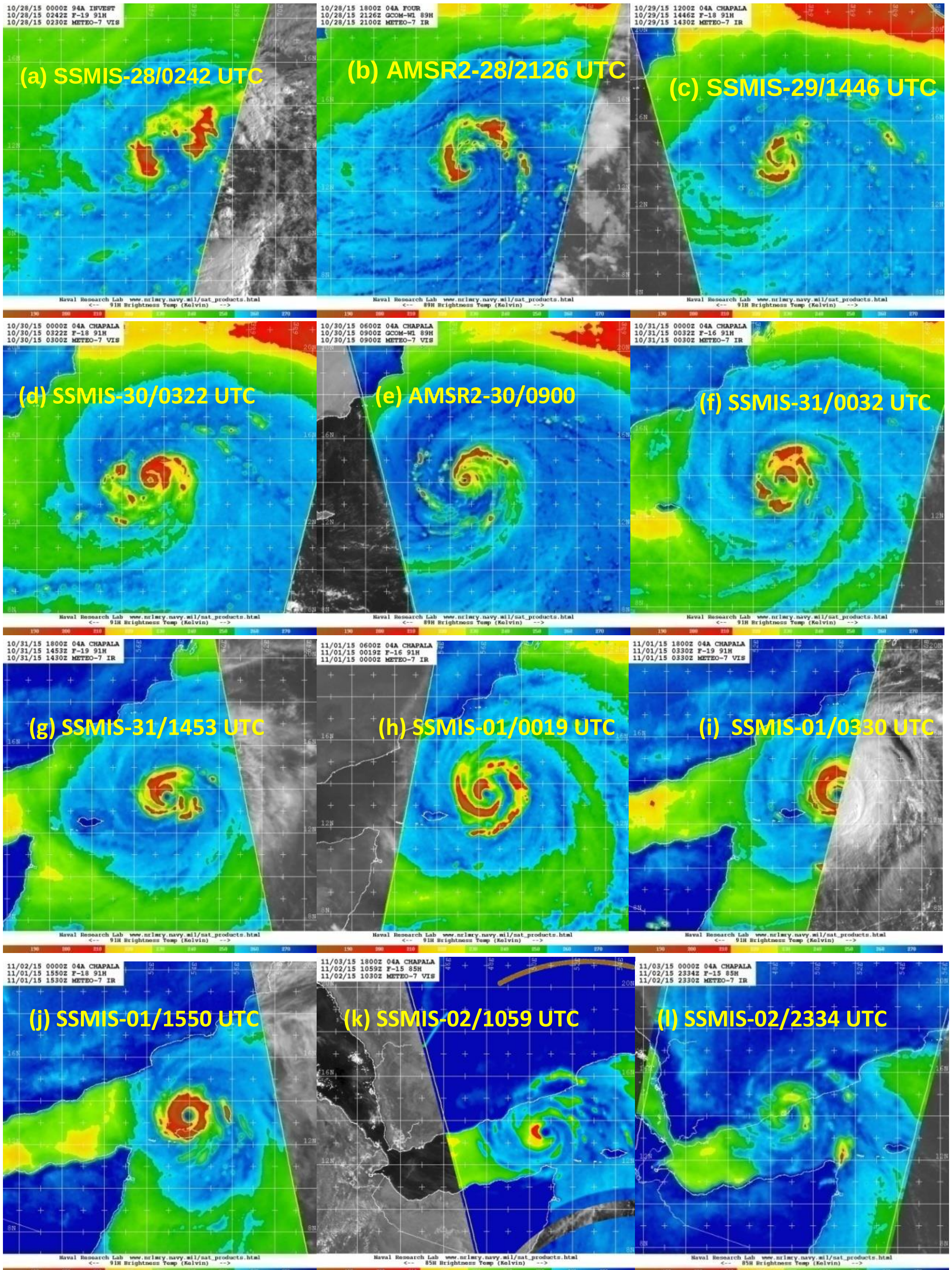


Fig.2.3.10 (a-l). Evolution of TC Chapala during28 Oct - 03 Nov 2015 based on microwave imageries (SSMIS / AMSR2).

(b) Microwave features and eye characteristics

Fig.2.3.10 (a-m) presents the SSMIS / AMSR2 microwave imageries depicting the organisation of convective clouds associated with the system. As seen, on 28th October, convective clouds organised from shear pattern to curved band pattern (a&b:28/0242 & 28/2126). On 29th, curved banding improved considerably and eye feature started appearing (c: 29/1446 UTC). Subsequently, as the system intensified, the eye feature became very well-defined and eye wall completely covered the eye (d: 30/0322 UTC). However, by 30/0900 UTC, the eye wall started opening (e), the eye became more and more exposed and an outer eye wall started forming on 31st (f: 31/0032 UTC). Thereafter, on 31/1453 UTC, the outer eye wall is observed to have shifted inwards towards the partially dissolved inner eye wall (g). On 1st November, by 01/0019 UTC, the inner eye wall has disappeared and the outer eye wall surrounds the eye (h). Associated with this eye wall replacement cycle, there has been a temporary weakening of the system on 30th. With the formation and strengthening of the secondary eye wall (i: 01/0330 UTC), the intensity of the system increased further on 31st October and 01st November. On 01/1530 UTC, the outer eye wall completely surrounds the eye and the system attained its mature stage. The eye diameter during this stage was about 37 km (j:01/1550 UTC). Subsequently, by 02/0300 UTC, the intensity of the system started decreasing and at 02/1059 UTC, most of the wall cloud portion had dissolved and a partial eye wall with an exposed eye is seen (k). As the system approached close to the coast, further disorganisation occurred due to land interaction (l: 02/2334 UTC).

2.3.6. Surface wind structure

The surface wind structure during the life period of ESCS, Chapala based on multi-satellite surface wind developed by CIRA, USA is shown in Fig. 2.3.11.

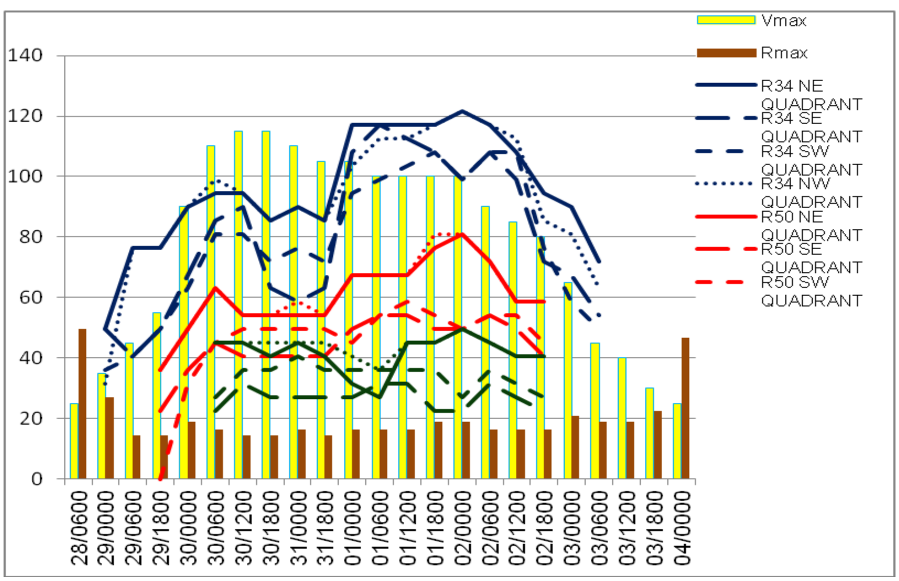


Fig. 2.3.11: Radius of34 knot (R34), radius of 50 knot (R50) & radius of 64 knot (R64), estimated maximum sustained surface winds (Vmax in knots) and Radius of Maximum winds (Rmax in nautical mile) based on multi-satellite surface wind (http://rammb.cira.colostate.edu/)

It can be seen that the radius of 34 kt (outer core size) winds was higher in northeast (NE) sector. It was maximum of about 120 nm during its mature stage. Also in the radius of 50 kt/64 kt (inner core size), the winds were higher in the northeastern sector as compared to the other sector. Further it can be seen that the size of the outer core gradually increased till 0600 UTC of 30th Oct., then it slightly decreased upto 1800 UTC of 30 Oct. followed by a sharp increase upto 0000 UTC of 1st Nov. The size then almost remained same upto 0000 UTC of 2nd Nov. and then gradually decreased. The change in the inner core (R50) was similar to that of R34 and the temporal variation in R64 was less. Similarly the Radius of Maximum Winds (RMW) did not show significant variation throughout the TC stage and it varied from 15-20 nm.

2.3.7.Dynamical features

The genesis of the system took place on 28th under favourable environmental conditions of high SST (around 30°C), low to moderate wind shear (10-20 knots), conducive MJO conditions (phase 2 and amplitude greater than 1).

The system was initially located along the southwestern periphery of an anticyclone to the northeast which steered the system northward / north-northwestward on 28th. Subsequently, from 29th onwards, the system was steered by another anti-cyclone located to the northwest of its centre. On 29th October, the system was located along the southeastern periphery of the western anti-cyclone which steered the system westward to west-southwestward and subsequently, during 30th October to 01st November also the system was tracking west to west-southwestward under its influence. On 2nd, the system centre was located along the southwestern periphery of this anti-cyclone and was steered west-northwestward to northwestward on 2nd and 3rd November.

During the period 28th October to 01 November, outflow above the system centre strengthened significantly. On 29th, the poleward outflow increased and subsequently, during 30th October to 01st November, the outflow from the system centre was enhanced radially in all directions due to significant favourable interaction with upper tropospheric trough and divergence associated with sub tropical westerly jet located to the northeast of the system centre and the system continued to intensify despite intrusion of cold air from the northwest. The system underwent rapid intensification during 29/0000-30/00000 UTC in association with lowering of vertical wind shear to about 5-10 knots near the system centre, enhanced poleward outflow associated with an upper air westerly trough located to the northeast of the system centre and continued prevalence of favourable MJO conditions. However, as the system tracked more and more westwards towards Yemen coast on 2nd November, it started weakening due to intrusion of cold and dry air and interaction with land.

Dynamical features observed in the IMD-GFS analysis of MSLP, 10m, 850 hPa, 500 hPa and 200 hPa winds based on 0000 UTC of 28-October to 03 November 2015 (Fig. 2.3.12 (i) to (vii)) are discussed herewith.

As seen, cyclogenesis of the system and its subsequent intensification is indicated by the model. On 28th and 29th, surface winds of about 30-35 kts are predicted and winds are stronger over the northeastern sector. The extent of subsequent intensification is not indicated clearly by the model. However, major synoptic features associated with movement and intensification of the system are predicted well. A deep amplitude westerly trough at 500 hPa level is located north-northeast / northeast of the system centre on 28th and 29th.

At 200 hPa level, northeast-southwest oriented westerly trough is located to the northeast of the system centre on 28th and 29th and poleward outflow from the system merges with the sub-tropical westerly jet located to the northeast of the system centre during 28th-31st. These features contributed significantly to enhanced deepening of the central pressure and hence intensification of the system. On 31st, associated with rapid intensification of the system, surface winds are symmetric about the centre.

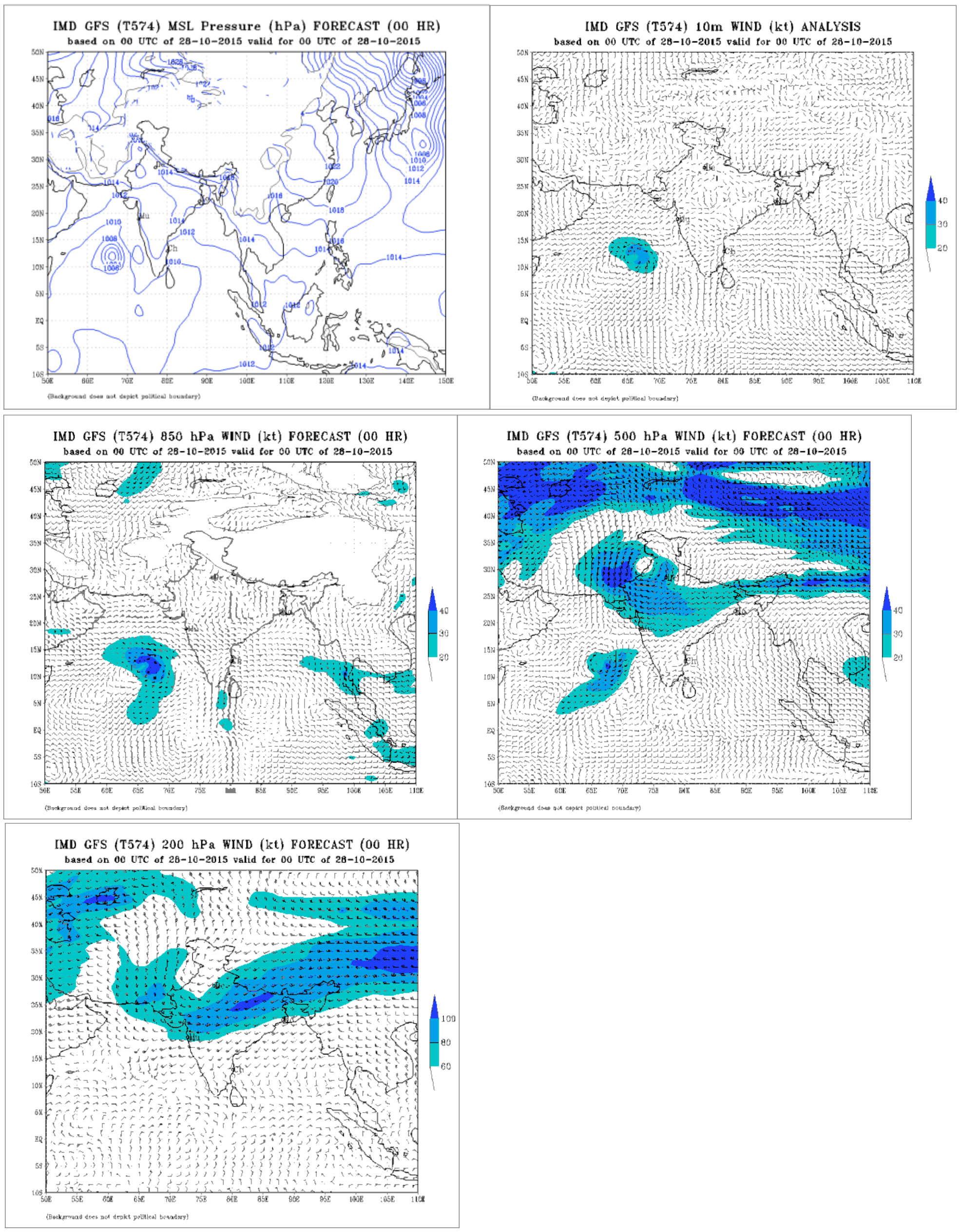


Fig 2.3.12 (i) IMD-GFS analyses of (a) MSLP and winds at (b) 10 m (c) 850 hPa (d) 500 hPa & (e) 200 hPa levels based on 0000 UTC of 28th October, 2015

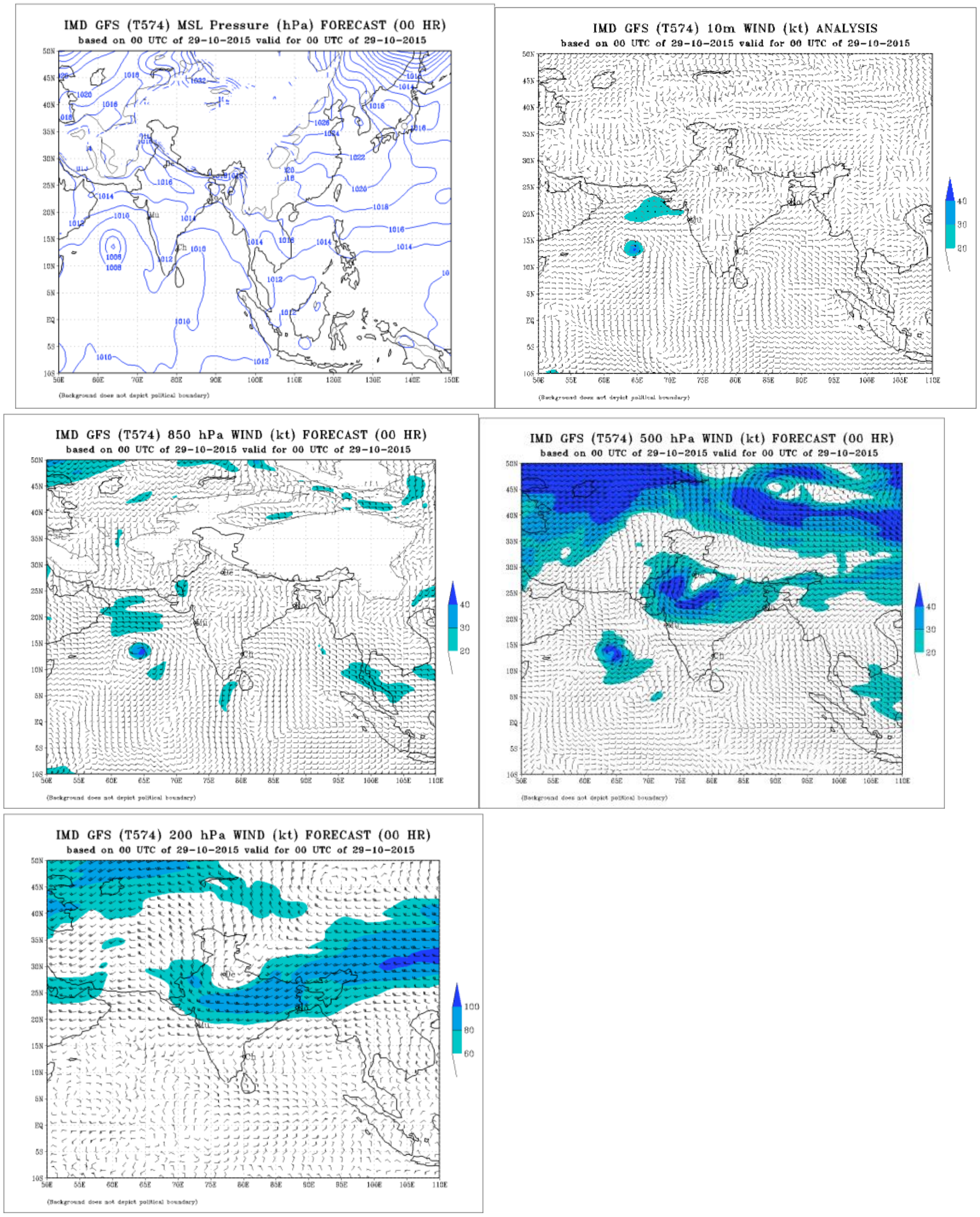


Fig2.3.12(ii)IMD-GFS analyses of (a) MSLP and winds at (b) 10 m (c) 850 hPa,(d) 500 hPa& (e) 200 hPa levels based on 0000 UTC of 29th October, 2015

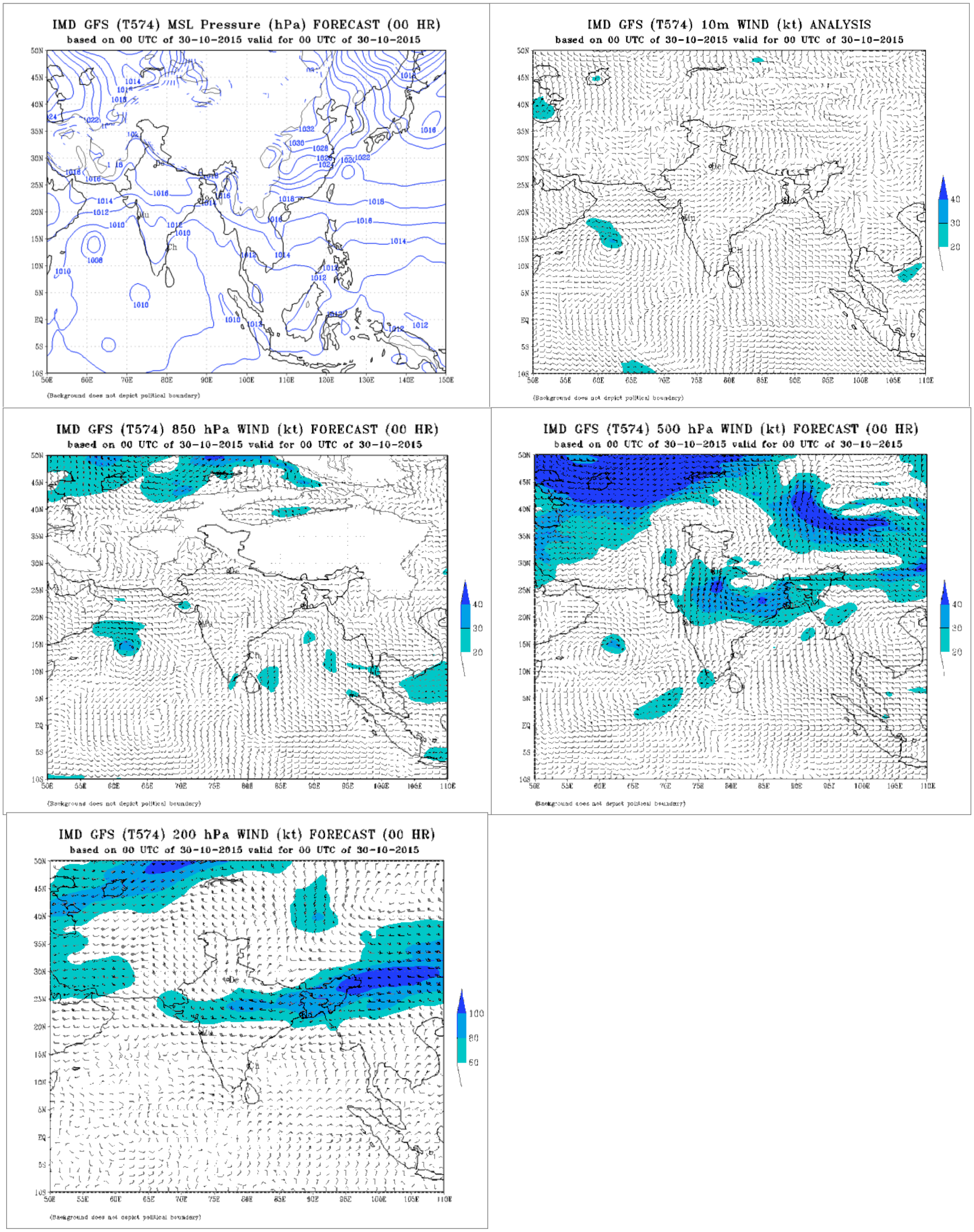


Fig 2.3.12 (iii) IMD-GFS analyses of (a) MSLP and winds at (b) 10 m (c) 850 hPa (d) 500 hPa & (e) 200 hPa levels based on 0000 UTC of 30th October, 2015

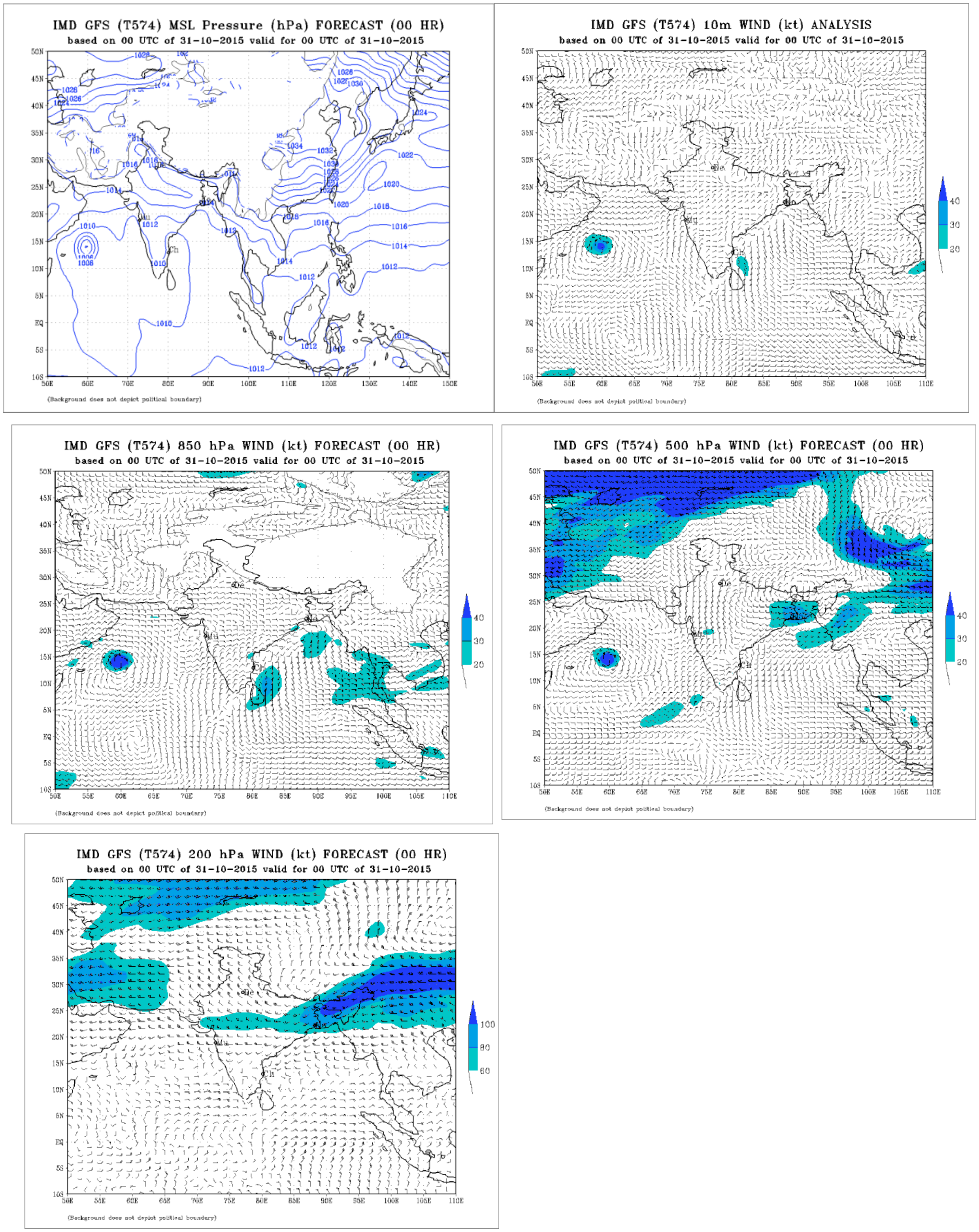


Fig 2.3.12 (iv) IMD-GFS analyses of (a) MSLP and winds at (b) 10 m (c) 850 hPa (d) 500 hPa & (e) 200 hPa levels based on 0000 UTC of 31st October, 2015

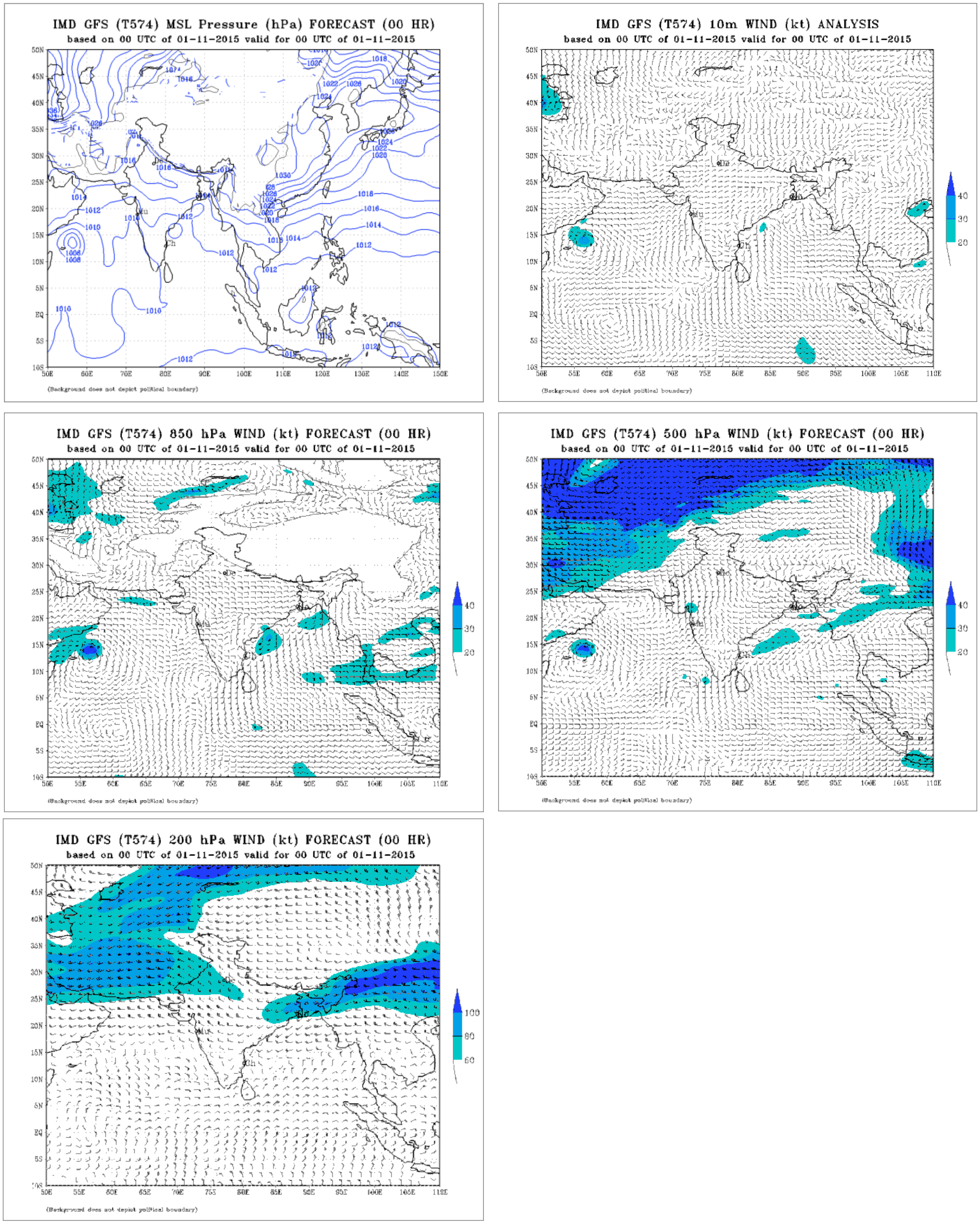


Fig 2.3.12 (v) IMD-GFS analyses of (a) MSLP and winds at (b) 10 m (c) 850 hPa (d) 500 hPa & (e) 200 hPa levels based on 0000 UTC of 1st November, 2015

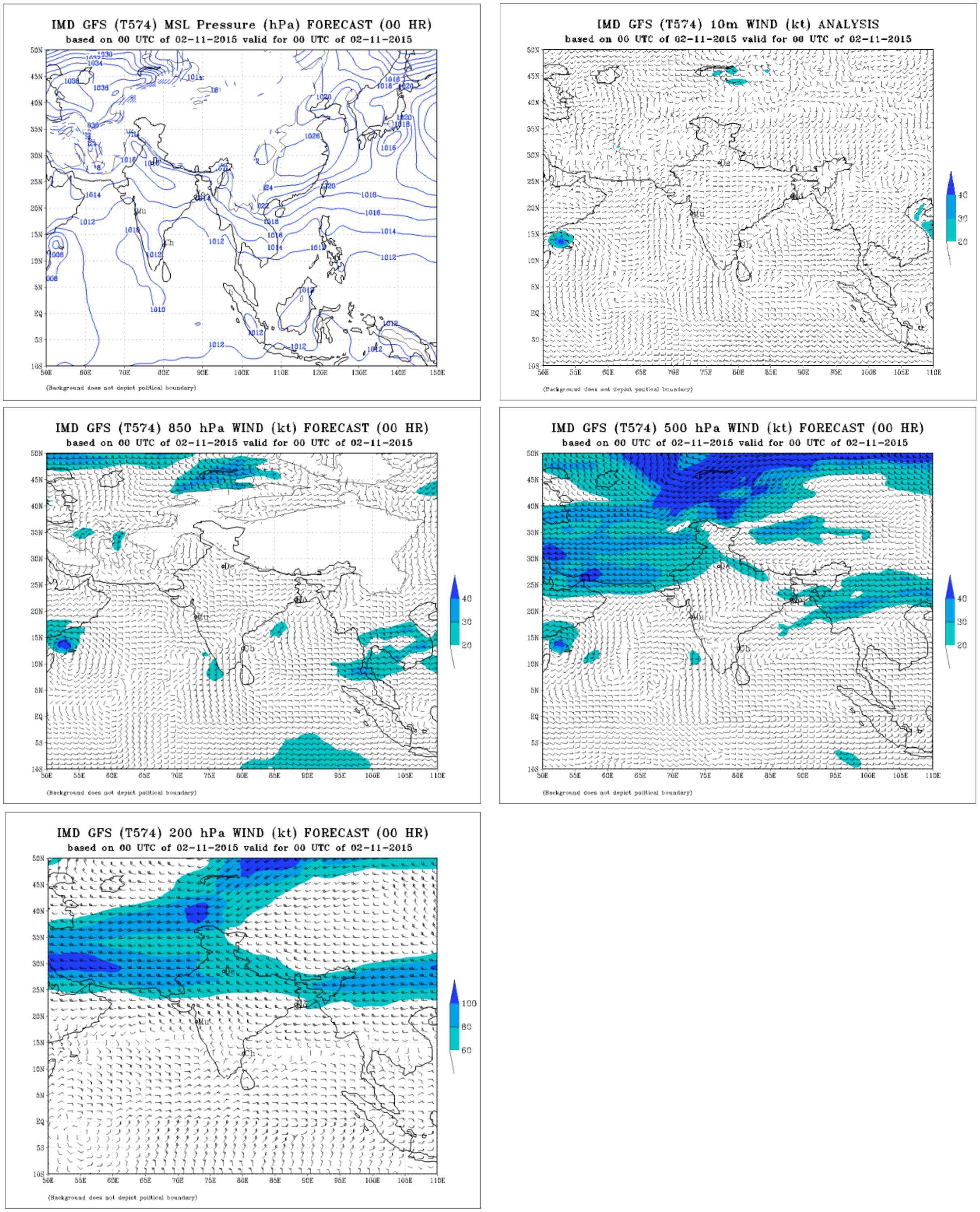


Fig 2.3.12 (vi) IMD-GFS analyses of (a) MSLP and winds at (b) 10 m (c) 850 hPa (d) 500 hPa & (e) 200 hPa levels based on 0000 UTC of 2nd November, 2015

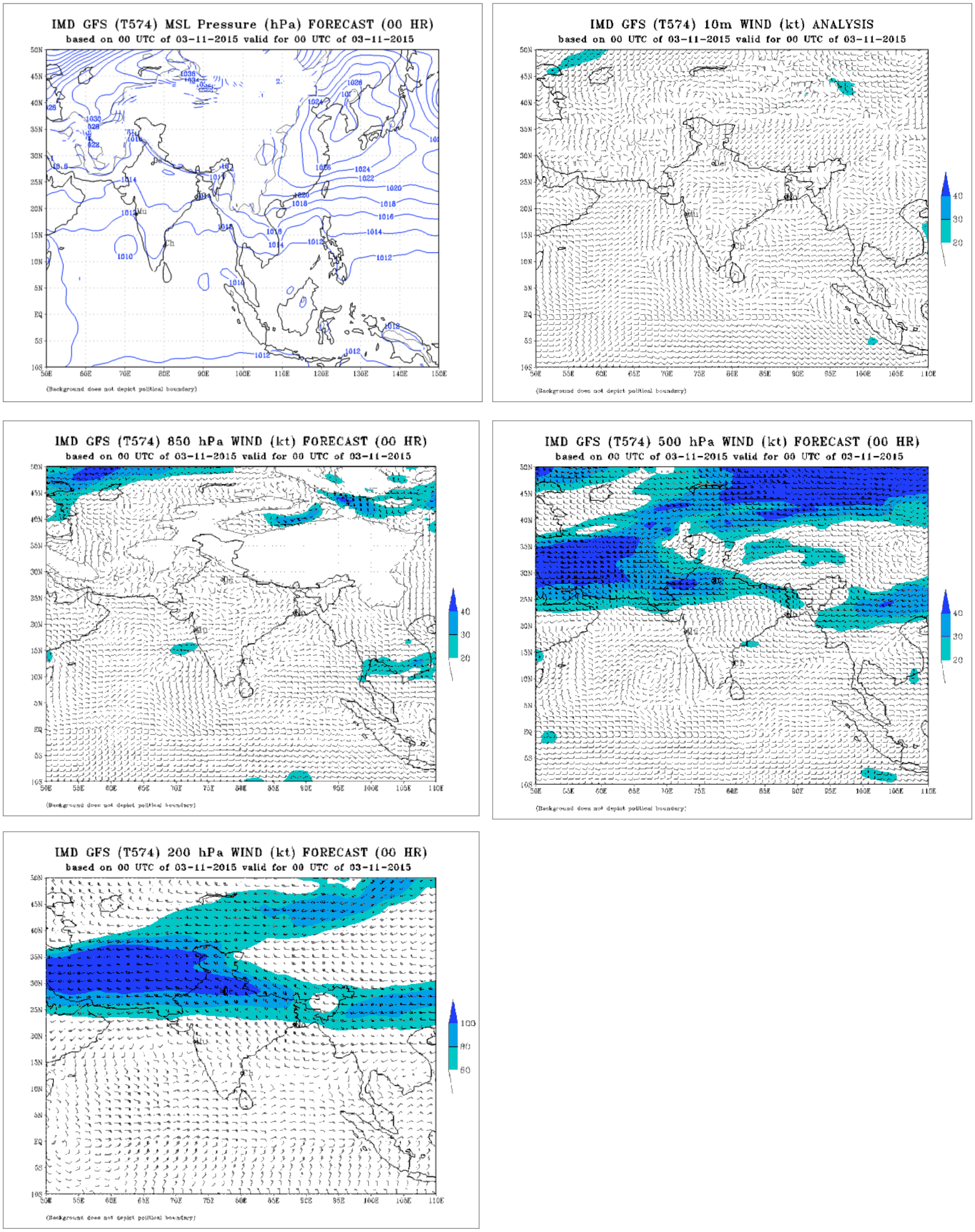


Fig 2.3.12 (vii) IMD-GFS analyses of (a) MSLP and winds at (b) 10 m (c) 850 hPa (d) 500 hPa & (e) 200 hPa levels based on 0000 UTC of 3rd November, 2015

2.3.8. Realized Weather:

Rainfall:

Rainfall associated with the system is depicted in Fig 2.3.13 (a-b) based on IMD-NCMRWF GPM merged gauge rainfall data.

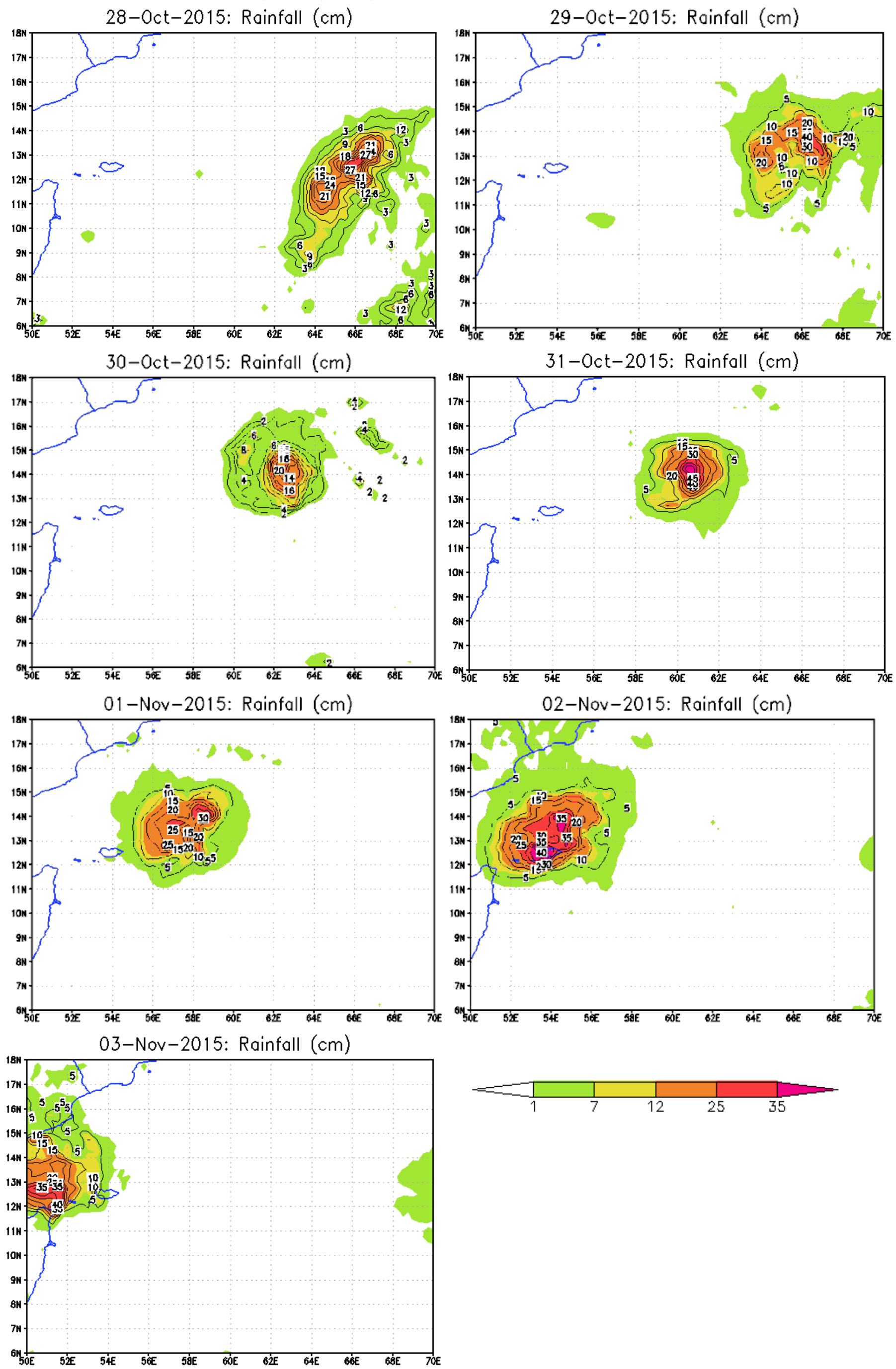


Fig. 2.3.13(a) IMD-NCMRWF GPM merged gauge rainfall data during the period 28 October to 03 November 2015 (with the rainfall categories as per IMD as per IMD's criteria)

During the initial stage of formation of the system, on 28th, rainfall belt was oriented along NE-SW and the rainfall maximum was observed to the northeast of the system centre. Subsequently, with the organisation of the system, convection became more and more organised and rainfall was symmetric about the centre on 31st. Rainfall of the order of 25-30 cm was realised near the core of the system on 28th and about 30-45 cm was realised in the wall cloud region during 29th October to 03rd November.

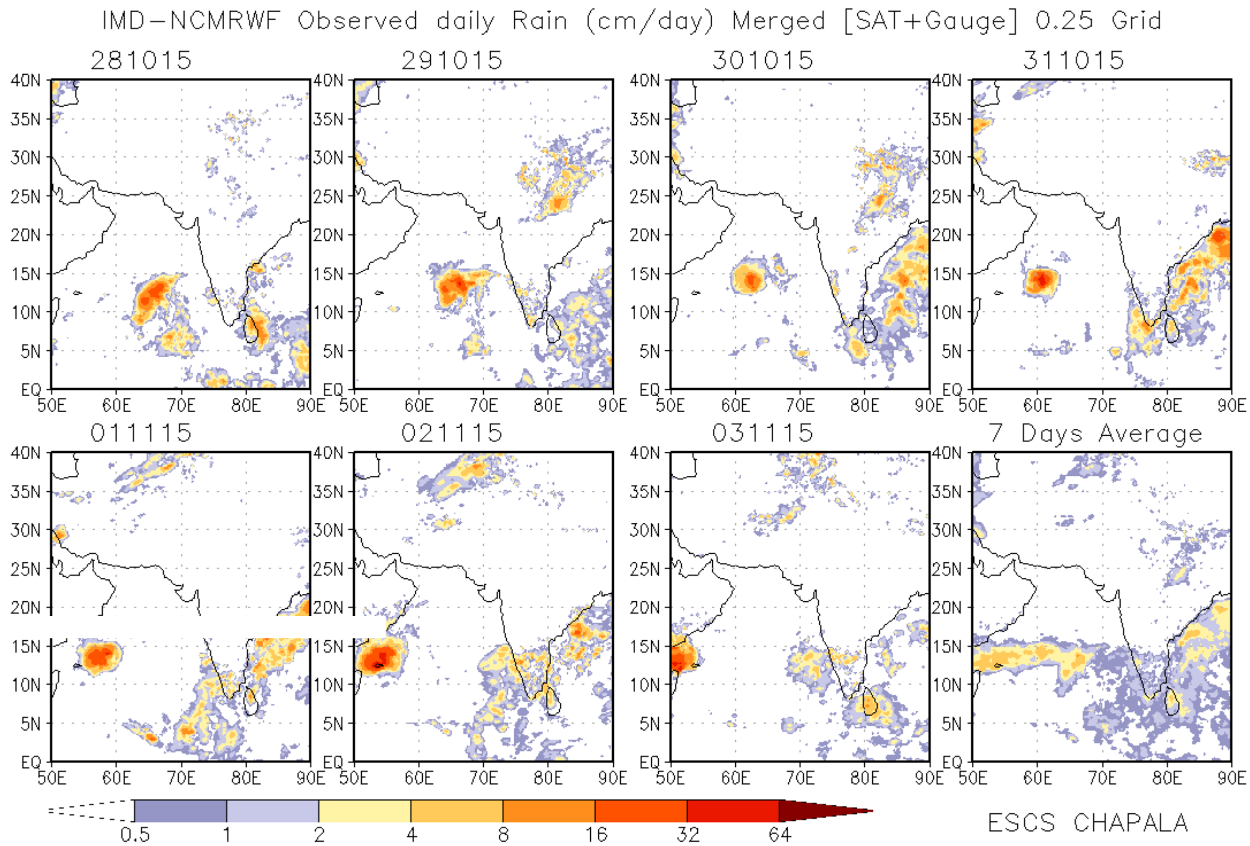


Fig. 2.3.13 (b) IMD-NCMRWF GPM merged gauge rainfall data during the period 28 October to 03 November 2015

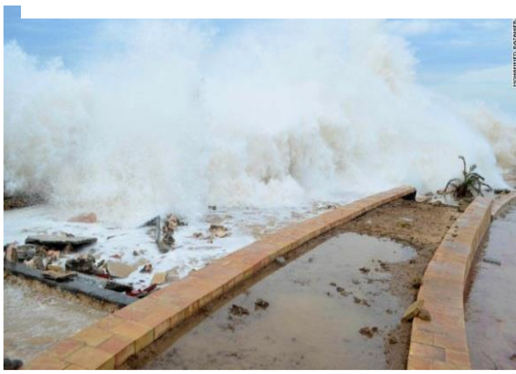
2.3.9. Damage due to ESCS Chapala

As per media and press report, ESCS Chapala killed at least five people and caused widespread damage as it brushed past Socotra Island of Yemen. More than 50,000 people in Yemen, including about 18,000 on Socotra, were displaced because of Cyclone Chapala.

Some photographs of damages caused by ECSC Chapala in Yemen are given in Fig. 2.3.14

Shore of Hadramout, damaged vehicles due to heavy rains and winds

Vehicles swept away by water in Socotra



Mukkala, 2nd Nov

Southern Yemen hit by flooding and high winds

City flooded in Mukkala, 3rd Nov

City flooded in Mukkala, 2nd Nov

Fig. 2.3.14: Damages caused due to ESCS Chapala over Yemen

2.4 Extremely Severe Cyclonic Storm, 'Megh' over the Arabian Sea (05-10 November 2015)

2.4.1 Introduction

A depression formed over the eastcentral Arabian Sea at 0000 UTC of 5th November from a low level circulation over Lakshadweep and neighbourhood. It moved westwards/west-southwestwards and intensified into a cyclonic storm (CS) at 1200 UTC of 5th November. It continued its west-southwestward movement and intensified into a severe cyclonic storm (SCS) at 0600 UTC of 7th, into a very severe cyclonic storm (VSCS) at 1500 UTC of 7th and rapidly intensified into an extremely severe cyclonic storm (ESCS) at 0300 UTC of 8th. Maintaining its peak intensity for a short period of about 6 hrs, it weakened gradually into a VSCS at 0000 UTC of 9th. From 0600 UTC of 9th, it exhibited west-northwestward movement, weakened rapidly into an SCS at 2100 UTC of 9th, into a CS at 0300 UTC of 10th and deep depression (DD) at 0600 UTC of 10th. It recurved northeastwards from 0300 UTC of 10th and crossed Yemen coast near latitude 13.4°N and longitude 46.1°E around 0900 UTC 10th as a DD. Continuing its northeastwards movement, it weakened into a depression at 1500 UTC of 10th and into a well marked low pressure area over Yemen and neighborhood at 1800 UTC of 10th.

The salient features of the system are as follows.

i. ESCS Megh occurred just after a week of formation of ESCS, Chapala over Arabian Sea. Also, ESCS Megh has been the first back to back cyclone after Chapala that reached Gulf of Aden and crossed Yemen within a week.
ii. ESCS Megh was the second ESCS after Chapala crossing Yemen coast in the satellite era. Chapala crossed Yemen coast close to the southwest of Riyan near 14.1^0N/48.65^0E during 0100-0200 UTC as a VSCS (with maximum sustained wind speed (MSW) of 65 knots) and Megh crossed Yemen coast near 13.4°N/46.1°E around 0900 UTC as a DD (with MSW of 30 knots).
iii. Unlike Chapala, ESCS Megh was a small core system with a pin hole eye.
iv. Megh maintained the intensity of ESCS for 18 hours (0803-0821) unlike Chapala which maintained the intensity of ESCS for 78 hours (3003-0209). The peak intensity in Megh was 95 knots for a period of 3 hours (0806-0809) against 115 knots for a period of 15 hours (3009-3100) in case of Chapala.
v. Lowest estimated central pressure (ECP) was 964 hPa with a pressure drop of 44 hPa unlike Chapala where it was 940 hPa with a pressure drop of 66 hPa.
vi. Like Chapala, ESCS Megh also experienced rapid intensification on 0000 UTC of 7th when its MSW increased from 45 knots to 85 knots at 0000 UTC of 8th (rise in wind speed 40 knots in 24 hours). During same period the ECP fell from 994 hPa to 974 hPa (20 hPa fall in 24 hours).
vii. ESCS Megh experienced rapid weakening over Gulf of Aden from 1800 UTC of 9th (MSW 65 knots) to 0600 UTC of 10th (MSW 35 knots), i.e. Megh experienced a fall in MSW by 30 knots in 12 hours.
viii. The ESCS Megh moved west to west-southwestwards throughout its life period till landfall over Yemen. While, ESCS Chapala moved initially north-northwestwards and then west-southwestwards to Yemen.

ix. Both ESCS Chapala and Megh could intensify upto the stage of ESCS under favourable environmental conditions, mainly low vertical wind shear (5-10 knots) around the system centre and the forward sector of the storm.
x. The system had the longest track length after VSCS Phet in 2010, as it travelled a distance of about 2307 km during its life period.
xi. The Accumulated Cyclone Energy (ACE) was about 8.2 X 10^4 $knot^2$ which is also the maximum after VSCS Phet in 2010 and ESCS Chapala in 2015 over the Arabian Sea.
xii. The Power Dissipation Index was 6.07 X 10^6 $knot^3$ which is the maximum after VSCS Phet in 2010 and ESCS Chapala in 2015 over the Arabian Sea.
xiii. The ESCS Megh had a life period of 5.7 days against long period average of 4.7 days in post-monsoon season for VSCS/ESCS over Arabian Sea)
xiv. The westward movement of the cyclone away from the Indian coasts was predicted from the first bulletin itself i.e. on 5^{th} November 2015 (0300 UTC). Every three hourly Tropical Cyclone Advisories were issued to WMO/ESCAP member countries, Yemen and Somalia.
xv. The numerical weather prediction (NWP) and dynamical statistical models provided reasonable guidance with respect to its genesis and track. However, most of the NWP and dynamical statistical models except HWRF could not predict the landfall and rapid intensification/ weakening of ESCS Megh.

Brief life history, characteristic features and associated weather along with performance of NWP and operational forecast of IMD are presented and discussed in following sections.

2.4.2 Monitoring of ESCS,'Megh'

The cyclone was monitored & predicted continuously since its inception by IMD. The forecast of its genesis on 5^{th} November, its track, intensity, landfall over Yemen were predicted with sufficient lead time. The observed track of the cyclone over AS during 5^{th} - 10^{th} November is presented in Fig.2.1.

At the genesis stage, the system was monitored mainly with satellite observations. Various national and international NWP models and dynamical-statistical models including IMD's and NCMRWF's global and meso-scale models, dynamical statistical models for genesis and intensity were utilized to predict the genesis, track and intensity of the cyclone. Tropical Cyclone Module, the digitized forecasting system of IMD was utilized for analysis and comparison of various models guidance, decision making process and warning product generation.

2.4.3 Brief life history

2.4.3.1 Genesis

An upper air cyclonic circulation in lower levels lay over southeast AS and adjoining Lakshadweep area on 1^{st} November. It moved west-nothwestwards and lay over eastcentral AS on 2^{nd}. It persisted over the same region on 3^{rd} and extended upto mid-tropospheric levels. Under its influence, a low pressure area formed over eastcentral AS on 4^{th}.On 0000 UTC of 5^{th}, the winds were higher over the northeastern sector. The sea surface temperature (SST) was 29^0C and the ocean thermal energy (OTE) was about 60-80 KJ/cm^2 around system centre. The vertical wind shear was about 5-10 knots (low) around the system centre. The low level relative vorticity was 50 KJ/cm^2. Lower level convergence was $5X10^{-5}s^{-1}$ and upper level divergence was $10X10^{-5}s^{-1}$. Vorticity at 850 hPa was 50 $X10^{-5}s^{-1}$. The low level relative vorticity and convergence had increased during previous 12 hrs. The upper tropospheric ridge at 200 hpa level ran along 16^0N. There was favourable poleward and westward outflow in association with the anti-cyclonic circulation lying to the northeast of the system centre alongwith this ridge. All these conditions led to intensification of the low pressure area into a depression at 0000 UTC of 5th. Considering the large scale features, the Madden Jullian Oscillation Index was in phase -2 over west-equatorial Indian Ocean with amplitude greater than 2. The Indian Ocean Dipole was positive, indicating higher warming over west equatorial Iindian Ocean, which helped in maintaining the warmer SST over AS even after passage of ESCS Chapala.

2.4.3.2 Intensification

Similar environmental conditions prevailed and the system intensified into a CS at 1200 UTC of 5th. Due to favourable large scale environmental features like MJO Index and weak vertical wind shear, the system experienced rapid intensification from 0300 UTC of 7th when its maximum sustained wind speed increased from 45 knots to 90 knots at 0300 UTC of 8th (rise in wind speed by 45 knots in 24 hours). During same period the ECP fell from 994 hPa to 968 (fall of 26 hPa in 24 hours). On 0300 UTC of 7th, the low level relative vorticity was 150 x 10^{-5} sec-1, convergence was 5-10 x 10^{-5} sec-1, and divergence was 30 x 10^{-5} sec-1. The SST around the system centre was 29°C. The OTE was about 35-50 KJ/cm^2 around system centre and 50-75 KJ/cm2 to west-southwest of the system centre The vertical wind shear was about 10 knots (low) around the system centre during the period of rapid intensification. The system reached its peak intensity (95 kt) at 0600 UTC of 8th.

The system started weakening from 1200 UTC of 8th. At 1200 UTC, the low level relative vorticity was 150 x 10^{-5} sec^{-1} and convergence was 20 x 10-5 sec-1. The upper level divergence decreased and was about 10 x 10^{-5} sec^{-1}. The SST around the system centre was 28°C. The OTE was 40-50 KJ/cm^2 around the system centre and then showed decreasing trends towards Gulf of Aden. The vertical wind shear was about 10 knots around the system centre. The low vertical wind shear was mitigating the adverse impact of cold and dry air intrusion from northwest. However, the system started weakening as it passed very close to Gulf of Aden around 0600 UTC of 8th and suffered land interaction. Also, it moved over an area with lower OTE over Gulf of Aden. Enhanced rapid weakening was observed from 1800 UTC of 9th due to land interaction with rugged terrain of Yemen, lower OTE over Gulf of Aden and dry air incursion. The system started weakening from 1200 UTC of 8th, the rate of weakening was slow till 1800 UTC of 9th. During this period the system passed close to the northern border of Socotra Island, moved into colder Gulf of Aden and the track was close to northern tip of Somalia, but the low vertical wind shear inhibited the adverse effect of cold and dry air from northwest in weakening the wall cloud region. It indicates that the internal dynamics played a significant role in maintaining intensity of the system apart from the external dynamics including environmental conditions. From 2100 UTC of 9th, the system exhibited rapid weakening as it lay over western part of Gulf of Aden and had interaction with rugged terrain of Yemen. It rapidly weakened from 65 kts at 1800 UTC of 9th to 30 kts at 0600 UTC of 10th just before landfall. The best track parameters of the systems are presented in Table 2.4.1**.** The total precipitable water imageries (TPW) during 5th to 10th November are presented in Fig.2.4.1 to show the role of TPW on intensification and weakening. The vertical wind shear during the life period of the system is shown in Fig. 2.4.2 to illustrate its impact on intensification and weakening.

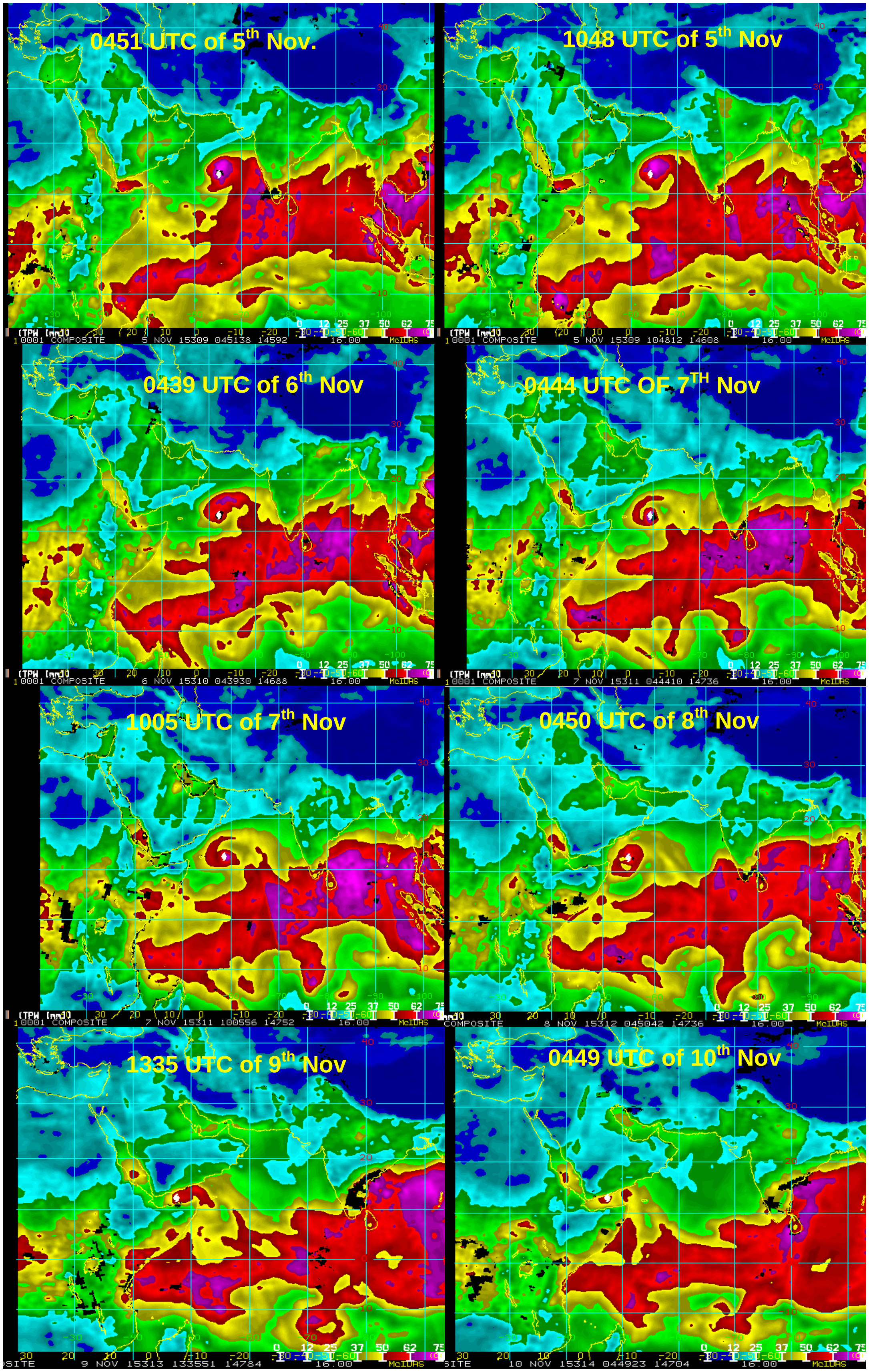


Fig.2.4.1 Total precipitable water imageries during 5th to 10th November 2015

2.4.3.3 MSW and estimated central pressure (ECP)

The lowest ECP and the MSW speed during the life cycle of ESCS Megh are presented in Fig. 2.4.3. The lowest ECP has been 964 hPa. The highest MSW speed was 95 knots during 0600 - 0900 UTC of 8th November. At the time of landfall, the ECP was 1003 hPa and MSW was 30 knots (deep depression) due to weakening of the system over Gulf of Aden. The figure also indicates that rapid intensification of the system commenced from 0300 UTC of 7th and continued upto 0600 UTC of 8$^{th.}$ It is mainly attributed to low vertical wind shear (05-10 kts) around the system centre and the forward sector of the system accompanied with favourable upper level divergence due to radial outflow. Also the large scale features like IOD and MJO were favouring amplification of the convection.

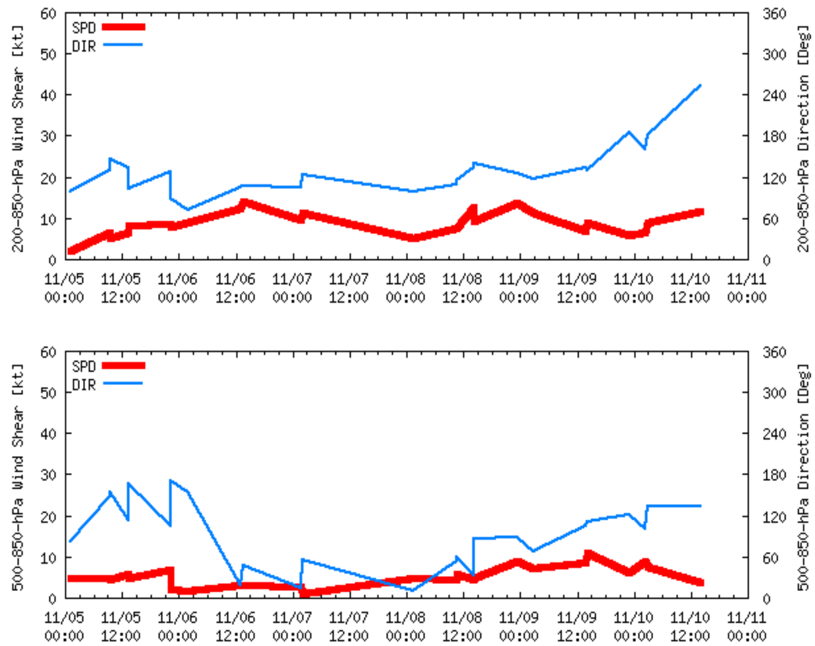


Fig. 2.4.2 Wind shear and wind speed in the middle and deep layer around the system during 05th to 10th Nov 2015.

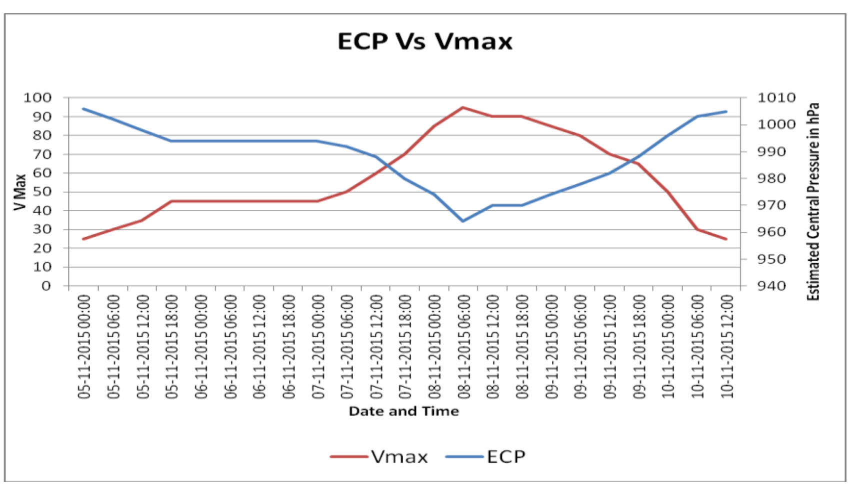


Fig. 2.4.3 Lowest estimated central pressure and the maximum sustained wind speed

2.4.3.4 Translational Speed and direction of movement

The six hourly translational speed and direction of movement of ESCS is presented in Fig. 2.4.4(a).

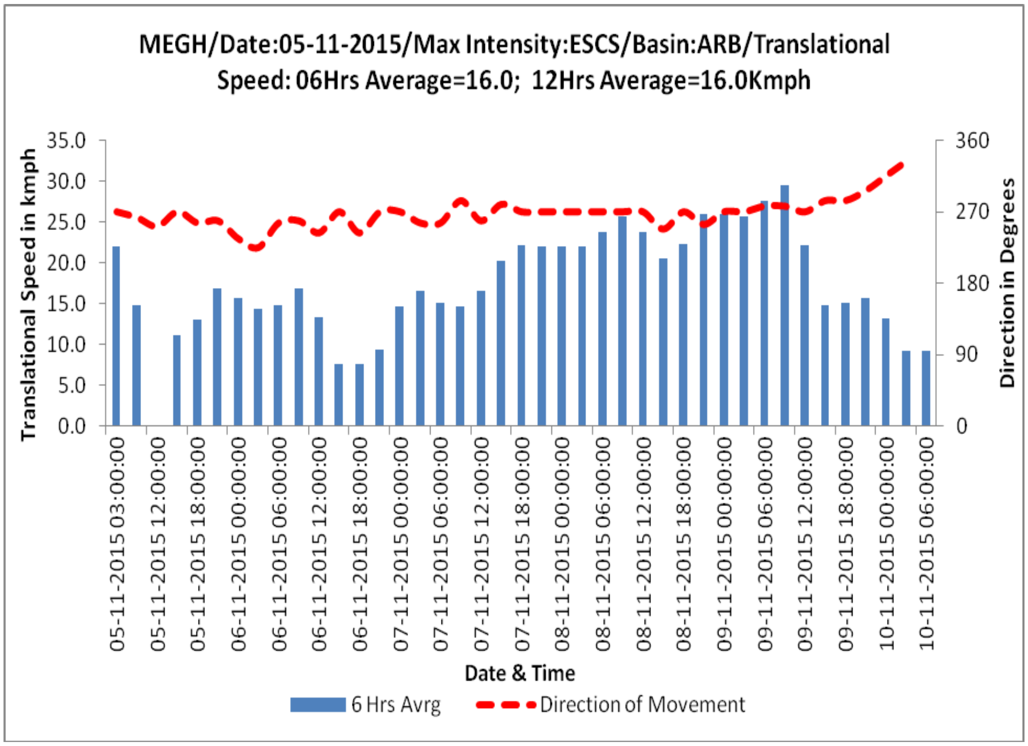


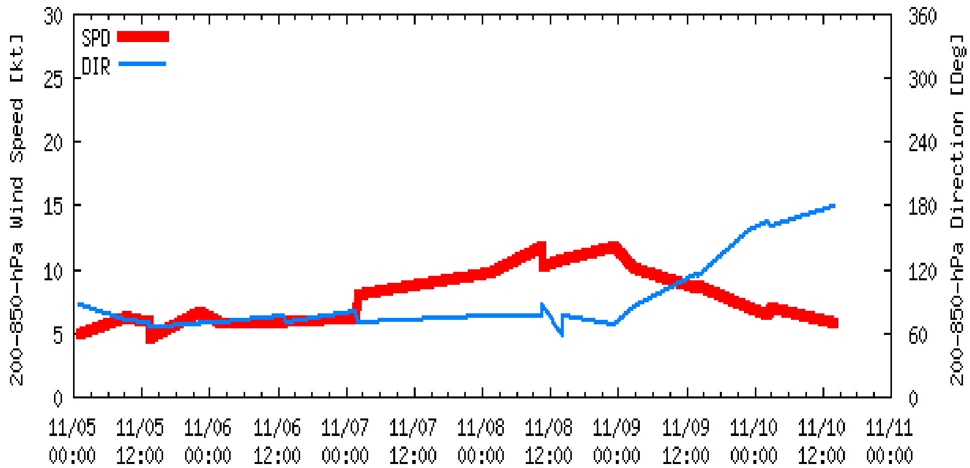
Fig.2.4.4 (a)Six hours average translational speed and direction of movement in association with ESCS Megh

The average translational speed of the system during entire life cycle was 16 kmph. However, on 8th and 9th November it moved with an average translational speed of 22.0 kmph and reached maximum of 29.6 kmph at 1200 UTC of 9th. It the decreased sharply till 1500 UTC of 9th (14.8 kmph). It moved slowly till 0000 UTC of 10th and then decreased sharply.

ESCS Megh moved west to west-southwestwards till 10th November, then recurved northeastwards and crossed Yemen coast. The upper tropospheric ridge was running along 16.0^{0}N in association with anti-cyclonic circulation lying to the northeast of the system centre. Under its influence, the system moved west/west-southwestwards till 0900 UTC of 9th November. Thereafter, the system started recurving northwards as the anticyclonic circulation moved northeastwards gradually from 9th with the ridge extending southwestwards towards northern tip of Somalia adjacent to Gulf of Aden on 0600 UTC of 10th leading to northeastwards recurvature. Continuing its northeastwards movement, the system crossed Yemen coast near lat. 13.4^{0}N/long.46.1^{0}E. To examine the steering flow, the mean wind speed and direction in middle and deep layer around the cyclone field is shown in Fig. 2.4.4(b). It indicates that the ESCS Megh was steered by middle to upper tropospheric winds.

The system had the longest track length after VSCS Phet in 2010 as it travelled a distance of about 2307 km during its life period (Chapala-2250 km).

To summarise, the genesis and intensification of the system just after the passage of ESCS Chapala, can be attributed to the favourable environmental conditions like vertical wind shear and large scale features like IOD and MJO.



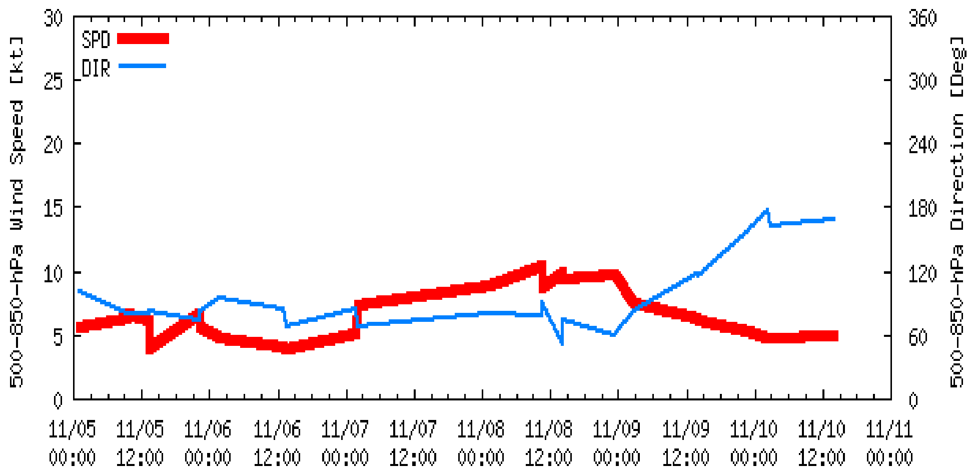


Fig.2.4.4 (b).Wind speed and direction in the middle and deep layer around the system during 05-10 Nov 2015.

Table 2.4.1 Best track positions and other parameters of Extremely Severe Cyclonic Storm (ESCS) 'MEGH' over the Arabian Sea during 05-10 November, 2015

Date	Time (UTC)	Centre lat.° N/ long.° E	C.I. NO.	Estimated Central Pressure (hPa)	Estimated Maximum Sustained Surface Wind (kt)	Estimated Pressure drop at the Centre (hPa)	Grade
05/11/2015	0000	14.1/66.0	1.5	1006	25	3	**D**
	0300	14.1/65.6	1.5	1004	25	4	D
	0600	14.1/64.8	2.0	1002	30	5	**DD**

	1200	14.0/64.0	2.5	998	35	7	**CS**
	1500	13.9/63.7	2.5	996	40	8	CS
	1800	13.9/63.4	3.0	994	45	10	CS
	2100	13.8/63.0	3.0	994	45	10	CS
06/11/2015	0000	13.7/62.5	3.0	994	45	10	CS
	0300	13.5/62.2	3.0	994	45	10	CS
	0600	13.2/61.9	3.0	994	45	10	CS
	0900	13.1/61.5	3.0	994	45	10	CS
	1200	13.0/61.0	3.0	994	45	10	CS
	1500	12.9/60.8	3.0	994	45	10	CS
	1800	12.9/60.6	3.0	994	45	10	CS
	2100	12.8/60.4	3.0	994	45	10	CS
07/11/2015	0000	12.8/60.1	3.0	994	45	10	CS
	0300	12.8/59.6	3.0	994	45	10	CS
	0600	12.7/59.2	3.0	992	50	12	**SCS**
	0900	12.6/58.8	3.5	990	55	16	SCS
	1200	12.7/58.4	3.5	988	60	18	SCS
	1500	12.6/57.9	4.0	984	65	22	**VSCS**
	1800	12.7/57.3	4.0	980	70	26	VSCS
	2100	12.7/56.7	4.5	976	80	32	VSCS
08/11/2015	0000	12.7/56.1	4.5	974	85	36	VSCS
	0300	12.7/55.5	5.0	968	90	40	**ESCS**
	0600	12.7/54.9	5.0	964	95	44	ESCS
	0900	12.7/54.2	5.0	964	95	44	ESCS
	1200	12.7/53.5	5.0	970	90	40	ESCS
	1500	12.7/52.9	5.0	970	90	40	ESCS
	1800	12.5/52.4	5.0	970	90	40	ESCS
	2100	12.5/51.7	5.0	970	90	40	ESCS
09/11/2015	0000	12.3/51.0	4.5	974	85	36	**VSCS**
	0300	12.3/50.3	4.5	976	80	32	VSCS
	0600	12.3/49.6	4.5	978	80	30	VSCS
	0900	12.4/48.8	4.0	980	75	28	VSCS
	1200	12.5/48.0	4.0	982	70	26	VSCS
	1500	12.5/47.6	4.0	986	65	22	VSCS
	1800	12.6/47.2	4.0	988	65	20	VSCS
	2100	12.7/46.8	3.5	990	60	18	**SCS**
10/11/2015	0000	12.9/46.4	3.0	996	50	14	SCS
	0300	13.1/46.2	3.0	998	40	12	**CS**

	0600	13.3/46.1	2.0	1003	30	5	**DD**
	0900	System crossed Yemen coast near Lat. 13.4°N/Long. 46.1°E around 0900 UTC					
	1200	13.6/46.5	-	1005	25	3	**D**
	1800	Weakened into a well marked low pressure area over Yemen and neighbourhood					

D: Depression, DD: Deep Depression, CS: Cyclonic Storm, SCS: Severe Cyclonic Storm, VSCS: Very Severe Cyclonic Storm, ESCS: Extremely Severe Cyclonic Storm

2.4.4. Climatological aspects

Climatologically, the severe cyclonic storms crossing Yemen coasts are very rare. Prior to Megh and Chapala, one SCS (May 1960) crossed Yemen coast during 1891-2014. The track of the SCS crossing Yemen coast is shown in Fig. 2.4.5.

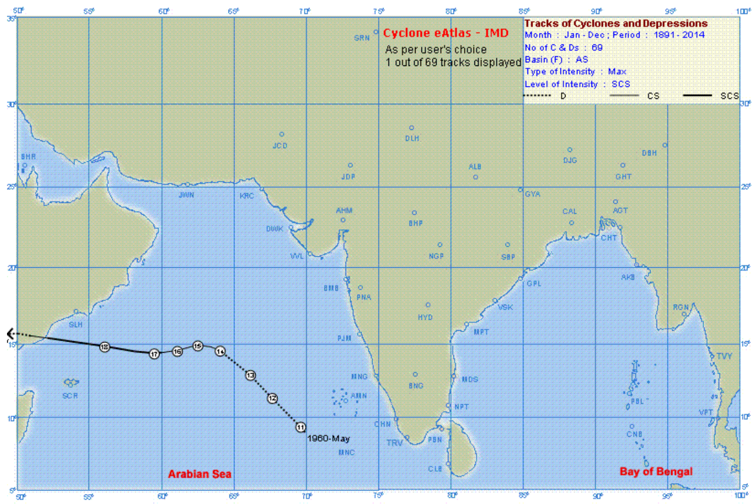


Fig. 2.4.5 Track of Severe cyclonic storm over Arabian Sea during the period 1891-2014 that crossed Yemen coast.

2.4.5 Features observed through satellite

Satellite monitoring of the system was mainly done by using half hourly Kalpana-1 and INSAT-3D imageries. Satellite imageries of international geostationary satellites Meteosat-7 and microwave & high resolution images of polar orbiting satellites DMSP, NOAA series, TRMM, Metops were also considered. Typical INSAT-3D visible/IR imageries, enhanced colored imageries and cloud top brightness tempearture imageries are presented in fig.2.4.6- 2.4.8.

2.4.5.1INSAT-3D features

Intensity estimation using Dvorak’s technique suggested that the system attained the intensity of T 1.5 on 0000 UTC of $5^{th.}$ Associated broken low and medium clouds with embedded moderate to intense convection lay over AS between latitude 12.0^{0}N to 17.5^{0}N and longitude 63.0^{0}E to 69.5^{0}E. Lowest cloud top temperature (CTT) was -81^{0}C. The cloud pattern was curved band type. Convection wrapped 0.5 on log 10 spiral. At 0600 UTC of $5^{th,}$

the system intensifiedto T2.0. At 1200 UTC of 5^{th}, the depth of convection increased, the lowest CTT was -83^{0}C and system intensified to T2.5. At 1800 UTC of 5^{th} convection further organised and the system intensified to T3.0. Convection wrapped 0.6 on log10 spiral. The system maintained its intensity till 0300 UTC of 7^{th}.

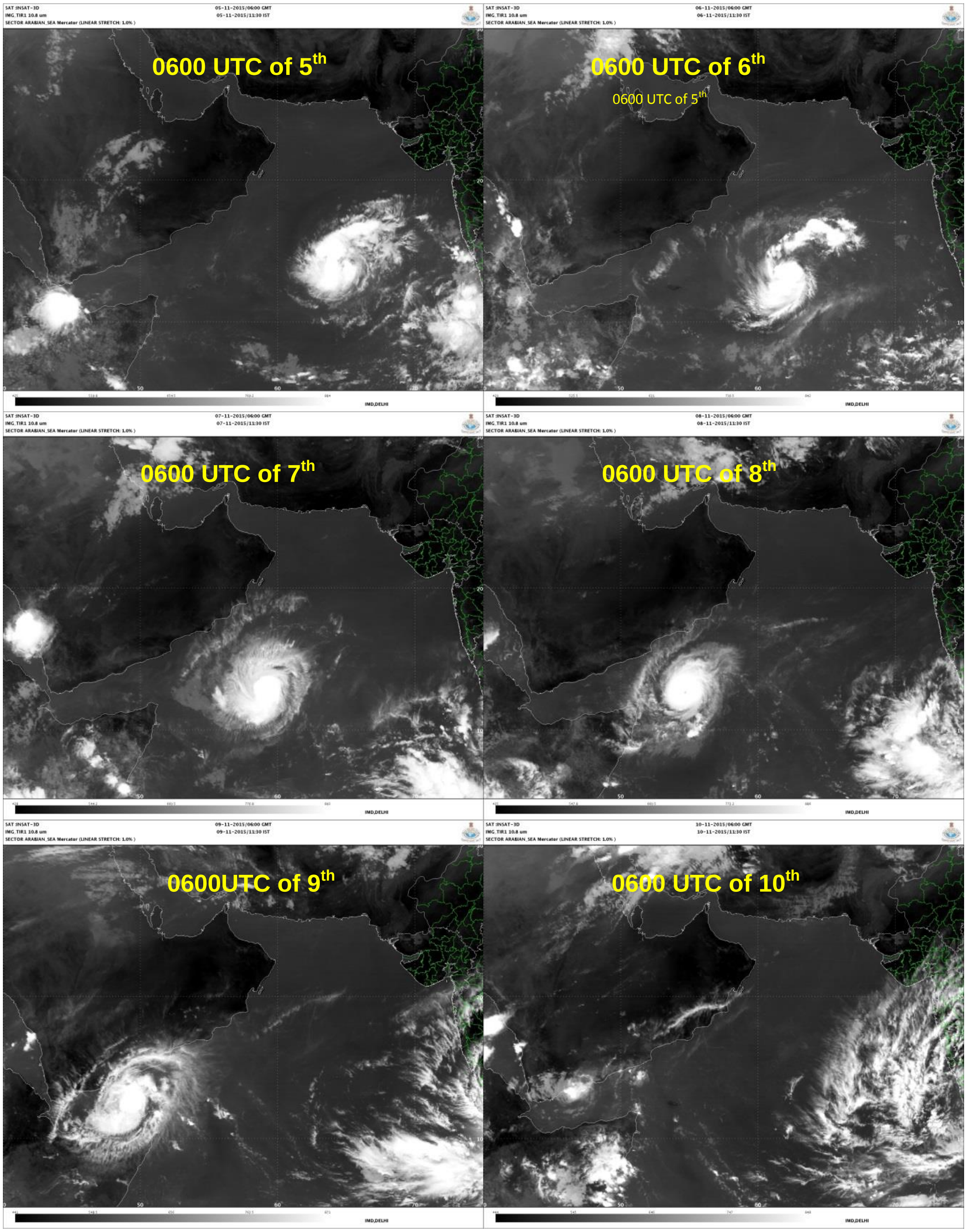


Fig2.4.6 INSAT-3D IR imageries based on 0600 UTC of 5^{th} to 10^{th} November 2015

At 0600 UTC of 7th, convection further organised and intensity was T3.0. Associated broken low and medium clouds with embedded intense to very intense convection lay over the area between latitude 10.5^{0}N to 15.0^{0}N and longitude 57.0^{0}E to 61.0^{0}E. Lowest CTT was -80°C. Ragged eye was seen. The system further intensified to T3.5 at 0900 UTC of 7th. The convection showed eye pattern. Ragged eye was seen in visible imagery. Lowest CTT in wall cloud region was -81°C. Area of convection extended between latitude 10.5^{0}N to 15.0^{0}N and longitude 56.5^{0}E to 60.5^{0}E. The system further intensified to T5.0 at 0300 UTC of 8th. Area of convection extended between latitude 11.0^{0}N to 14.5^{0}N and longitude 54.0^{0}E to 57.0^{0}E. Eye was seen in both visible and IR imageries. Lowest CTT in wall cloud region was -85°C. From 1200 UTC of 8th, the system started weakening. Lowest CTT in wall cloud region was -84°C. The clouds started disorganising. At 1430 UTC, the system lost its distinct eye feature in IR imagery. Thereafter the system underwent rapid weakening from 1800 UTC of 9th.

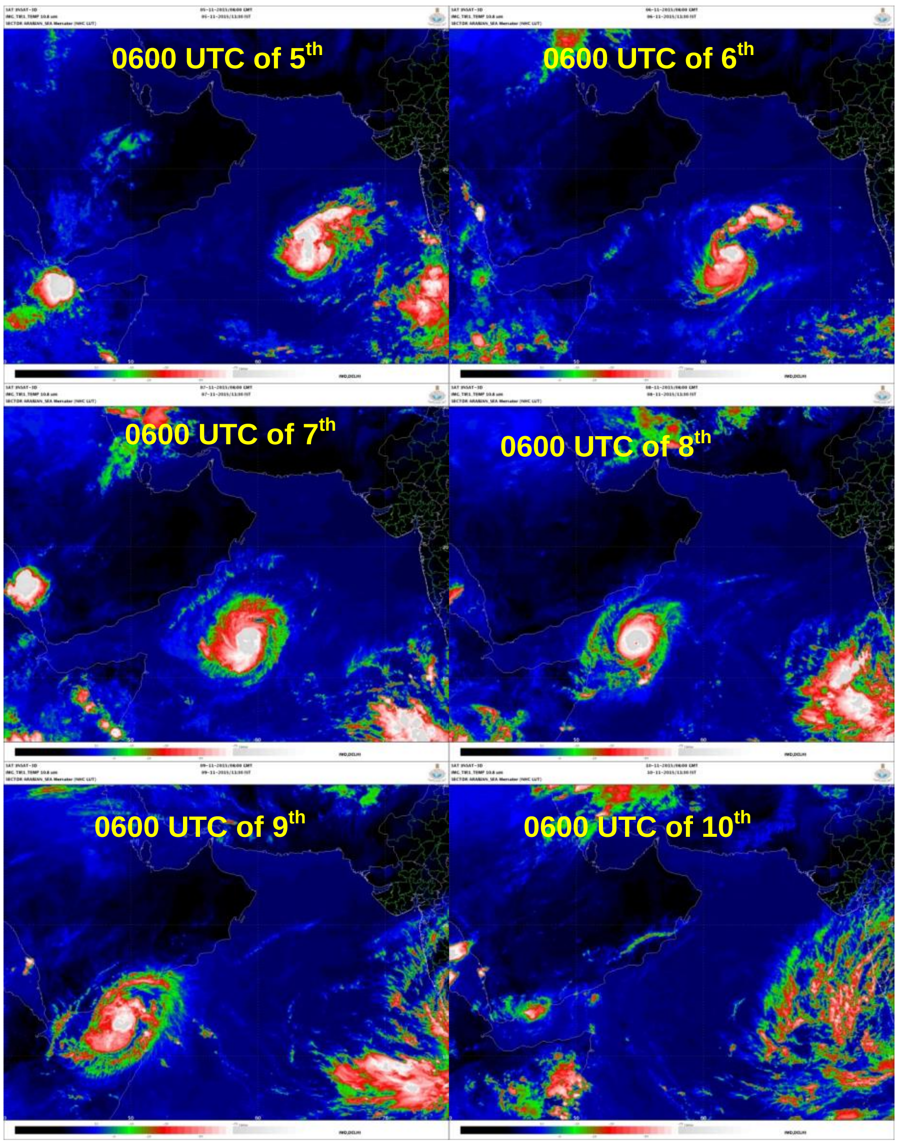


Fig.2.4.7 INSAT-3D enhanced colored imageries based on 0600 UTC of 5th to 10th November 2015

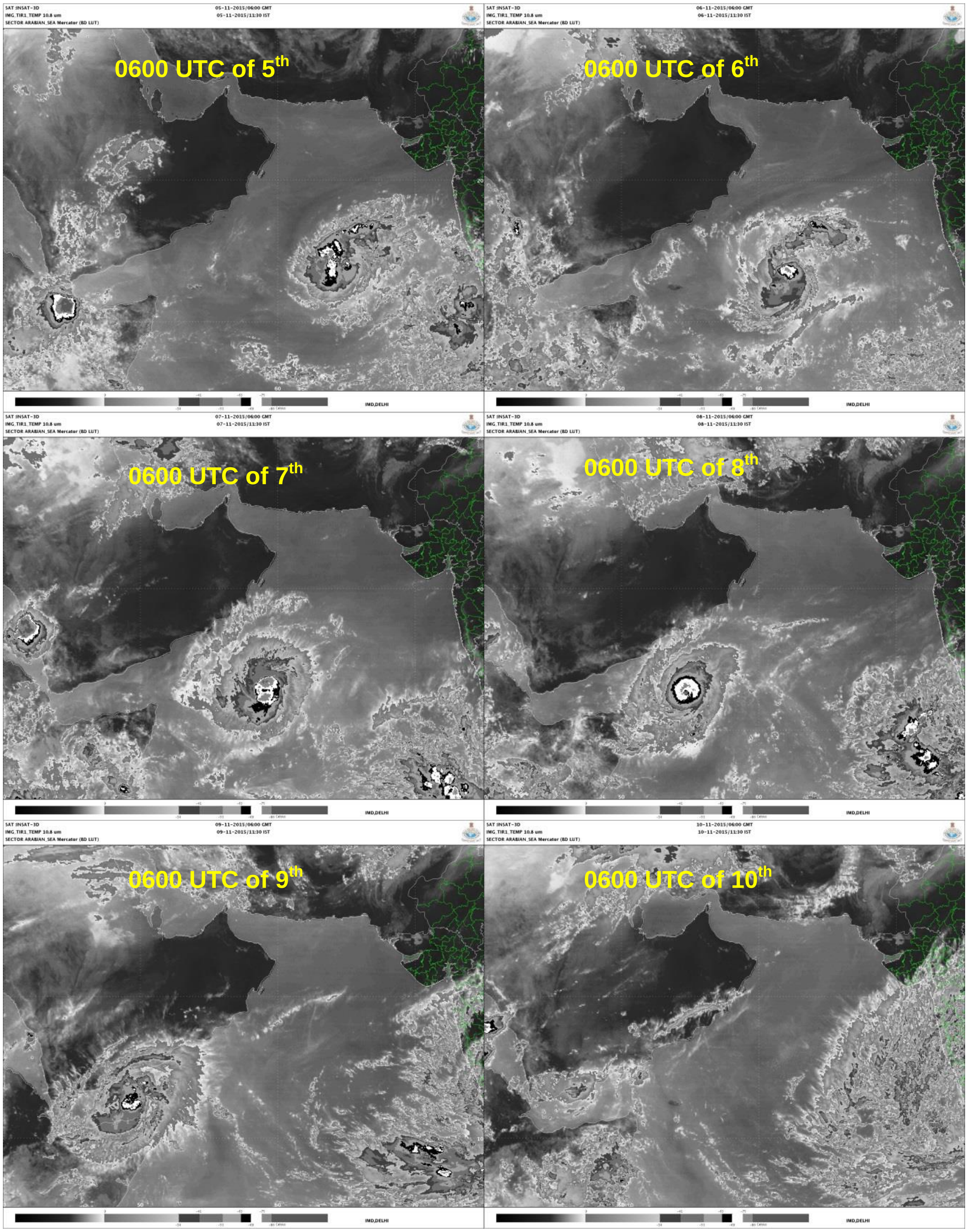


Fig. 2.4.8 INSAT-3D cloud top brightness temperature imageries based on 0600 UTC of 5-10 November 2015

2.4.5.2 Microwave features

SSMIS, AMSR2 and WINDSAT(37) microwave imageries of the ESCS Megh covering its life period from 05th to 10th November 2015 are presented in Fig.2.4.9 .

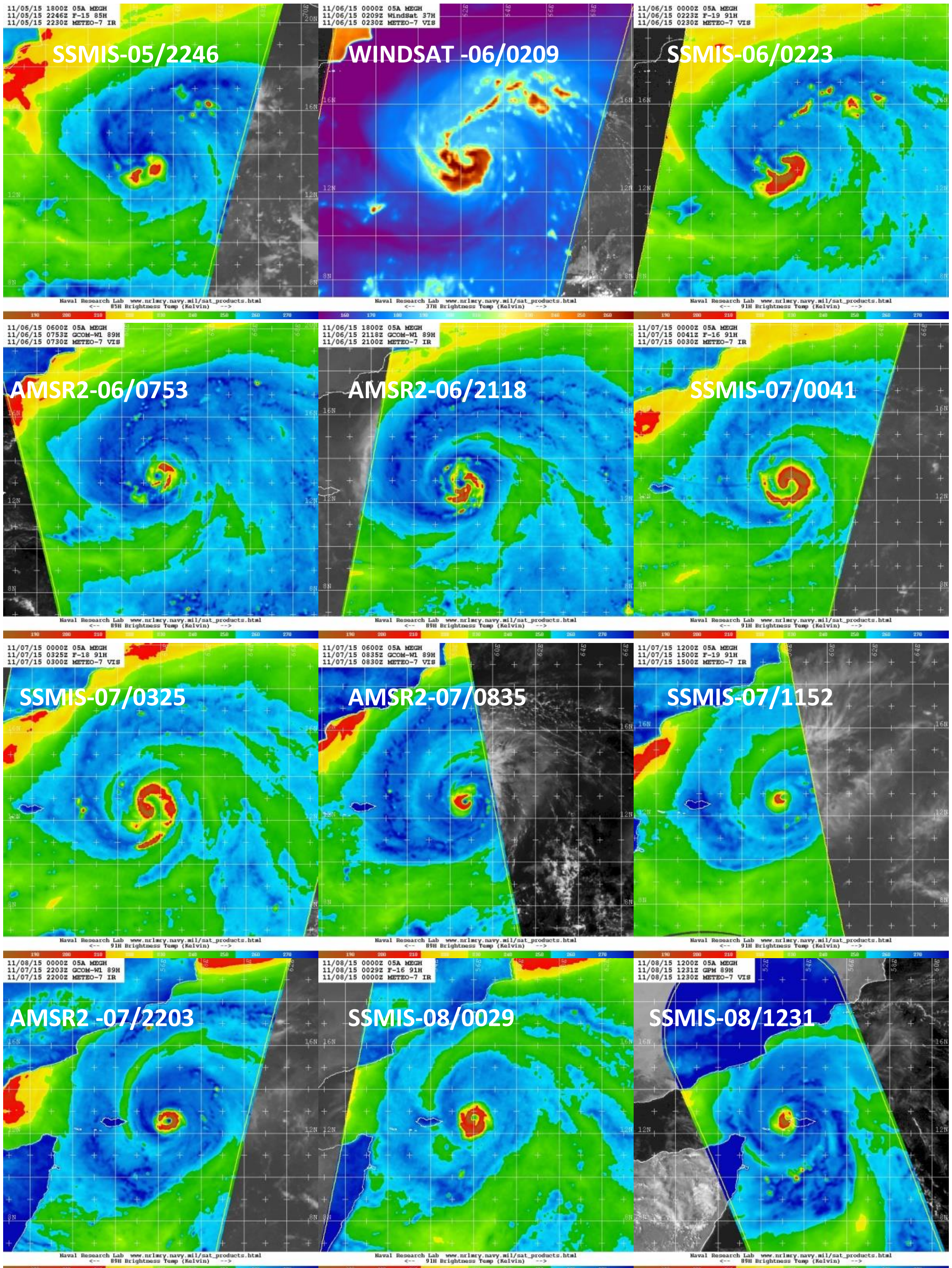


Fig. 2.4.9 Typical microwave imageries during 5th to 8th November 2015 in association with ESCS Megh.

On 05th and 06th, organisation of convective clouds along curved band is seen. On 06th/0753 UTC, formation of eye and development of wall cloud are observed. On 07th, the wall cloud region developed further and expanded. It is observed to spiral inwards cyclonically and completely covering the eye by 08th/0029 UTC. However, by 08th/1231 UTC, the eye-wall opened and the eye became exposed. Subsequently, disorganisation of convective clouds took place, eye became ill-defined and the system underwent rapid weakening on 09th (from T.5.0 at 09/0000 UTC to T 2.5 at 10/0000 UTC).

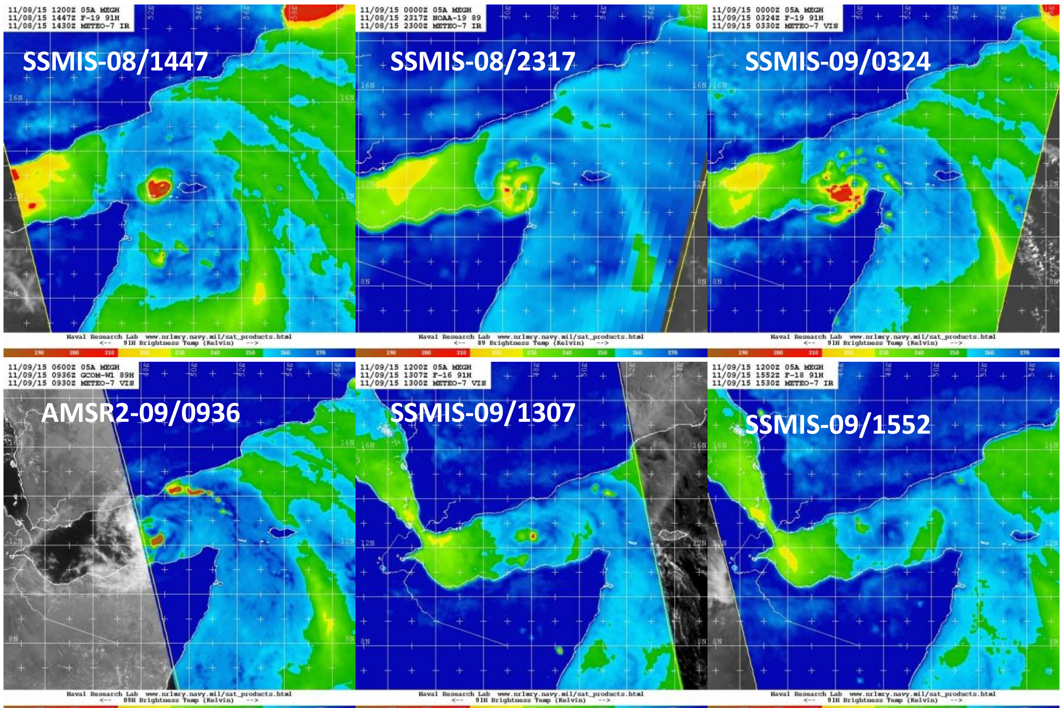


Fig. 2.4.9 (contd.) Typical microwave imageries during 8th to 9th November 2015 in association with ESCS Megh.

2.4.6 Surface wind structure

The surface wind structure during the life period of ESCS, Megh based on multi-satellite surface wind developed by CIRA, USA is shown in Fig. 2.4.10. It can be seen that the radius of 34 kt (outer core size) winds was higher in northeast (NE) sector. It was maximum of about 125 nm during its mature stage. Also in the radius of 50 kt/64 kt (inner core size), the winds were higher in the northeastern sector as compared to the other sector. The size of the system was maximum, especially in northeast quadrant at 0600 UTC of 9th November, while the intensity was decreasing gradually. Then it decreased sharply to 63 nm at 1200 UTC of 9th. The size then remained same upto 1800 UTC of 9th Nov. and then gradually decreased. The change in the inner core (R50) was similar to that of R34 and the temporal variation in R64 was less. The radius of maximum winds (RMW) remained almost same till 1800 UTC of 6th November. It then decreased gradually reaching minimum of 8nm at 1800 UTC of 8th, as the cyclone experienced rapid intensification from 0300 UTC of 7th to 0300 UTC of 8th. It then increased with weakening of the system from 1200 UTC of 8th. It was one of the lowest RMW, as the cyclone was associated with one of the smallest eye or a pin hole eye.

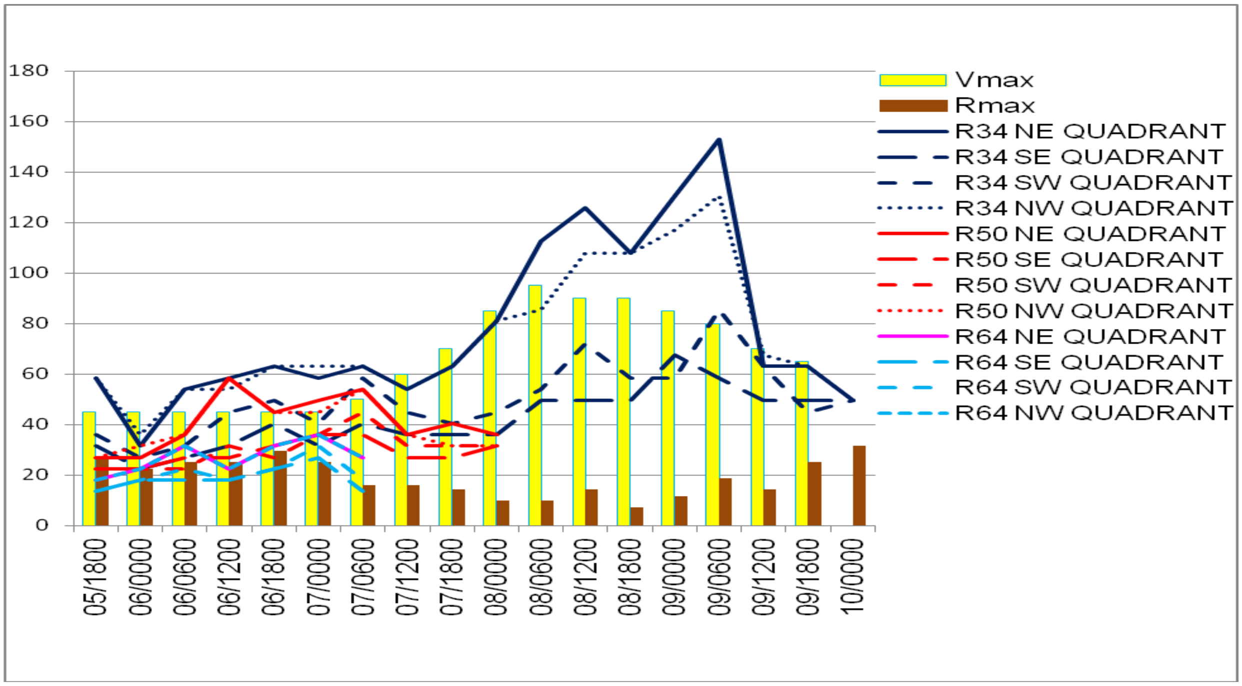


Fig. 2.4.10 Radius 34 knot (R34), radius of 50 knot (R50) & radius of 64 knot (R64), estimated maximum sustained surface winds (Vmax in knots) and Radius of Maximum winds (Rmax in nautical mile) based on multi-satellite surface wind (http://rammb.cira.colostate.edu/)

2.4.7 Dynamical features

To analyse the dynamical features, the mean sea level pressure (MSLP), 10 metre wind and winds at 850, 500 & 200 hPa levels based on 0000 UTC of 5th to 10th November are presented in fig. 2.11.11 (a-f). From the analysis of MSLP and 10m wind, it is observed that the GFS model underestimated the intensification of the system. However, it could detect the genesis at 0000 UTC of 5th November with the formation of 2 closed isobars at the interval of 2 hPa and ECP of 1008 hPa against the best track ECP of 1006 hPa. It could detect the movement towards Yemen coast across the Gulf of Aden, but could not predict the landfall. Though the centre based on GFS analysis lay to the south of the best track. The rapid intensification on 7th and rapid weakening on 10th could not be detected. The associated cyclonic circulation extended upto mid-tropospheric levels. Considering the upper tropospheric wind analysis, ridge over AS ran along 15.0^{0}N throughout the life period at 200 hPa level. At 500 hPa level, it ran along 18.0^{0}N during 5th to 7th and along 20.0^{0}N during 8th to 10th November. Under the influence of this ridge, northerly to northeasterly winds prevailed over the cyclone field leading to west-southwestwards movement of the system. From the GFS analysis, it can be concluded that the system was steered west-southwestwards by the lower mid-tropospheric winds. However, on 10th November the system recurved northeastwards which can be associated with the upper tropospheric flow at 200 hPa level.

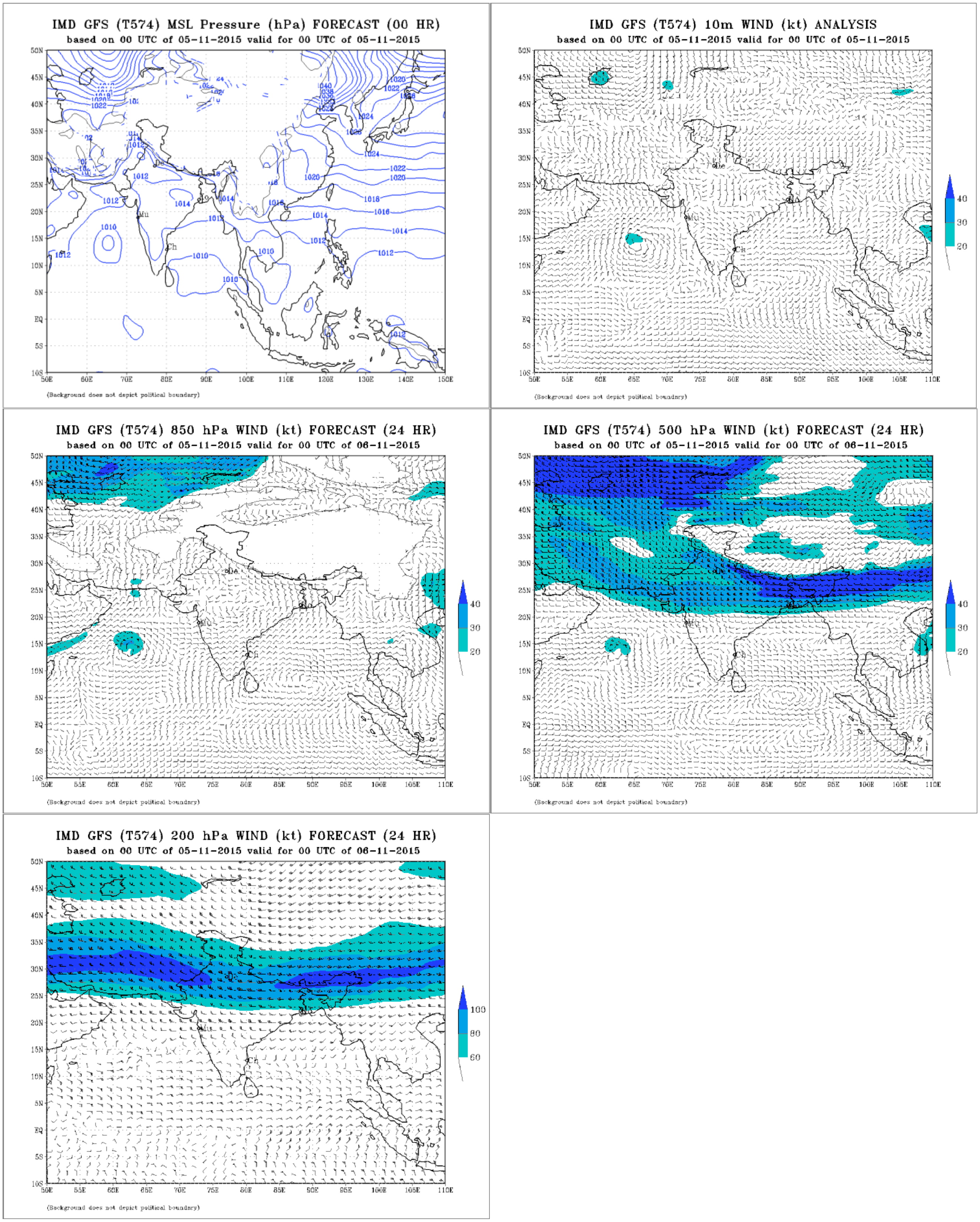


Fig.2.4.11(a) IMD GFS analysis of MSLP, 10m wind and winds at 850, 500 & 200 hPa levels based on 0000 UTC of 5th November.

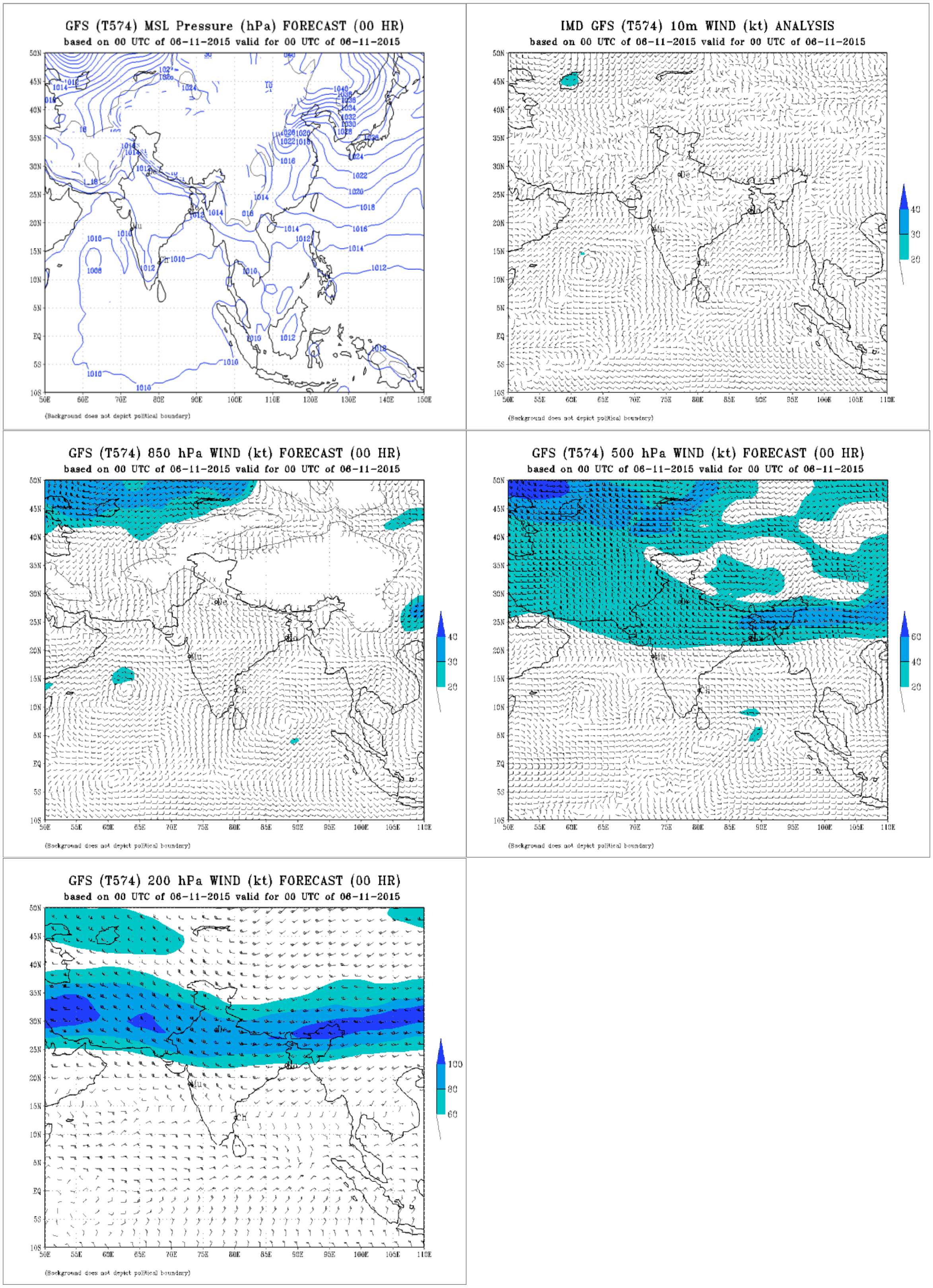


Fig.2.4.11(b) IMD GFS analysis of MSLP, 10m wind and winds at 850, 500 & 200 hPa levels based on 0000 UTC of 6th November.

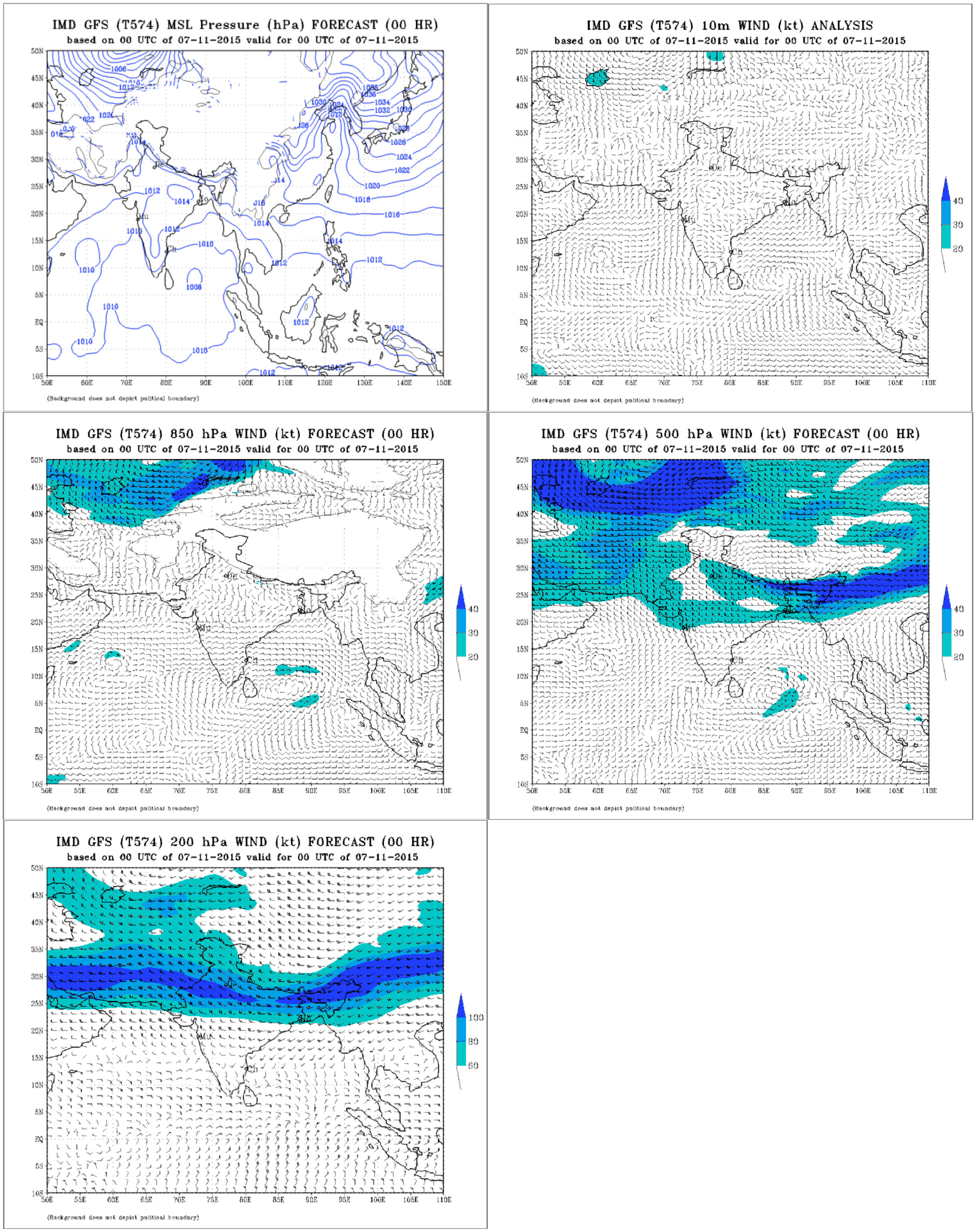


Fig.2.4.11(c) IMD GFS analysis of MSLP, 10m wind and winds at 850, 500 & 200 hPa levels based on 0000 UTC of 7th November.

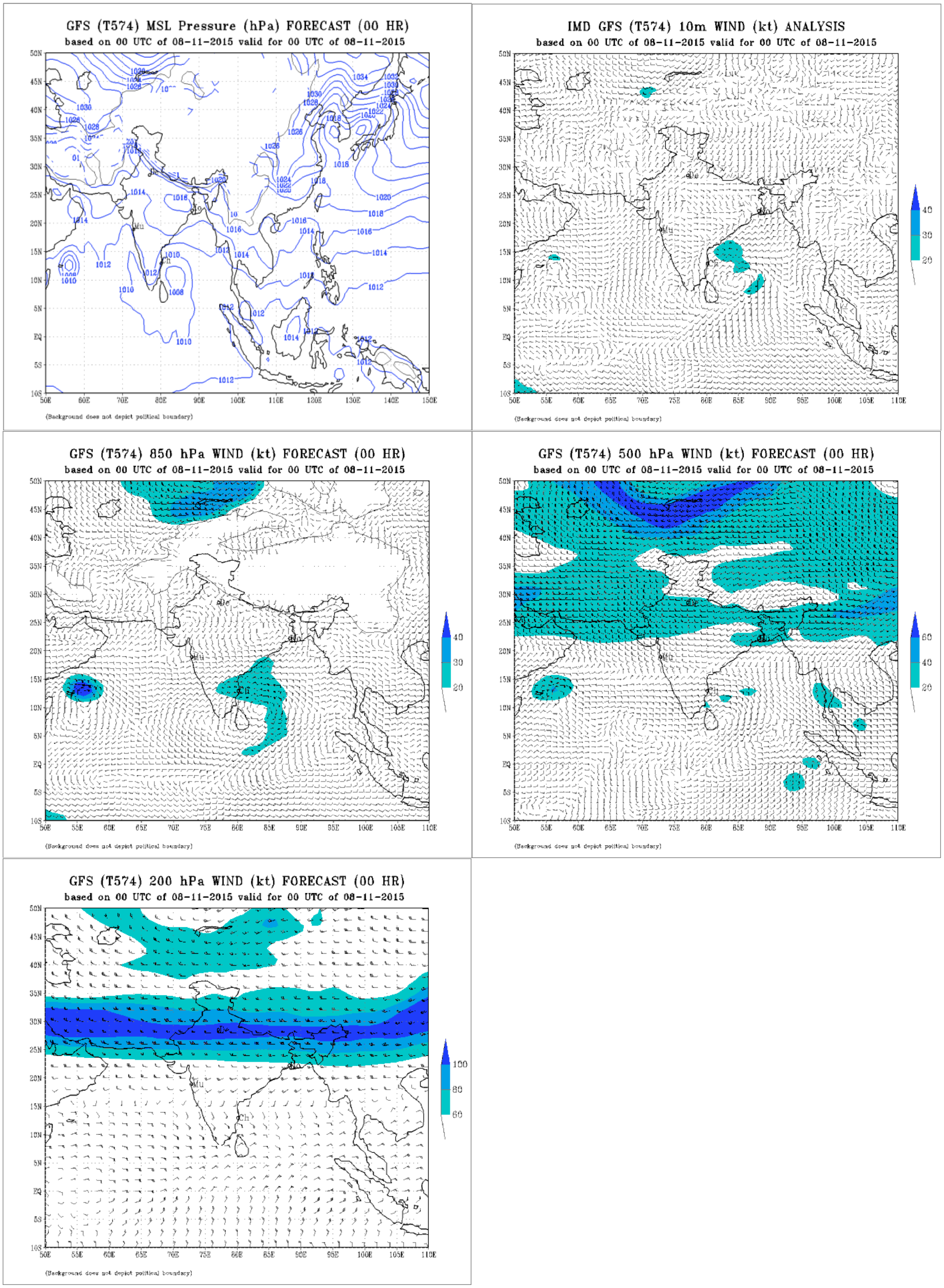


Fig.2.4.11(d) IMD GFS analysis of MSLP, 10m wind and winds at 850, 500 & 200 hPa levels based on 0000 UTC of 8th November.

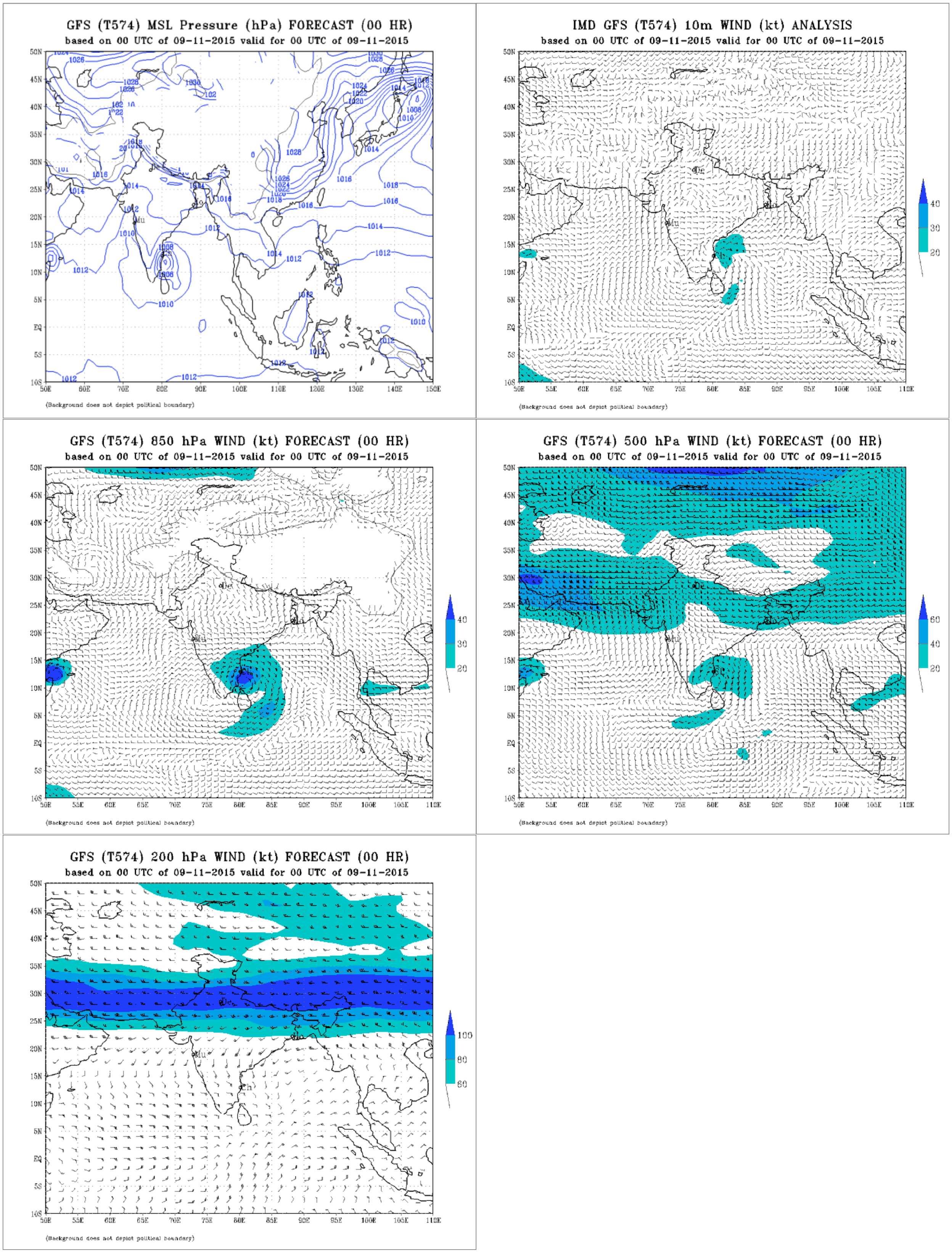


Fig. 2.4.11(e) IMD GFS analysis of MSLP, 10m wind and winds at 850, 500 & 200 hPa levels based on 0000 UTC of 9th November.

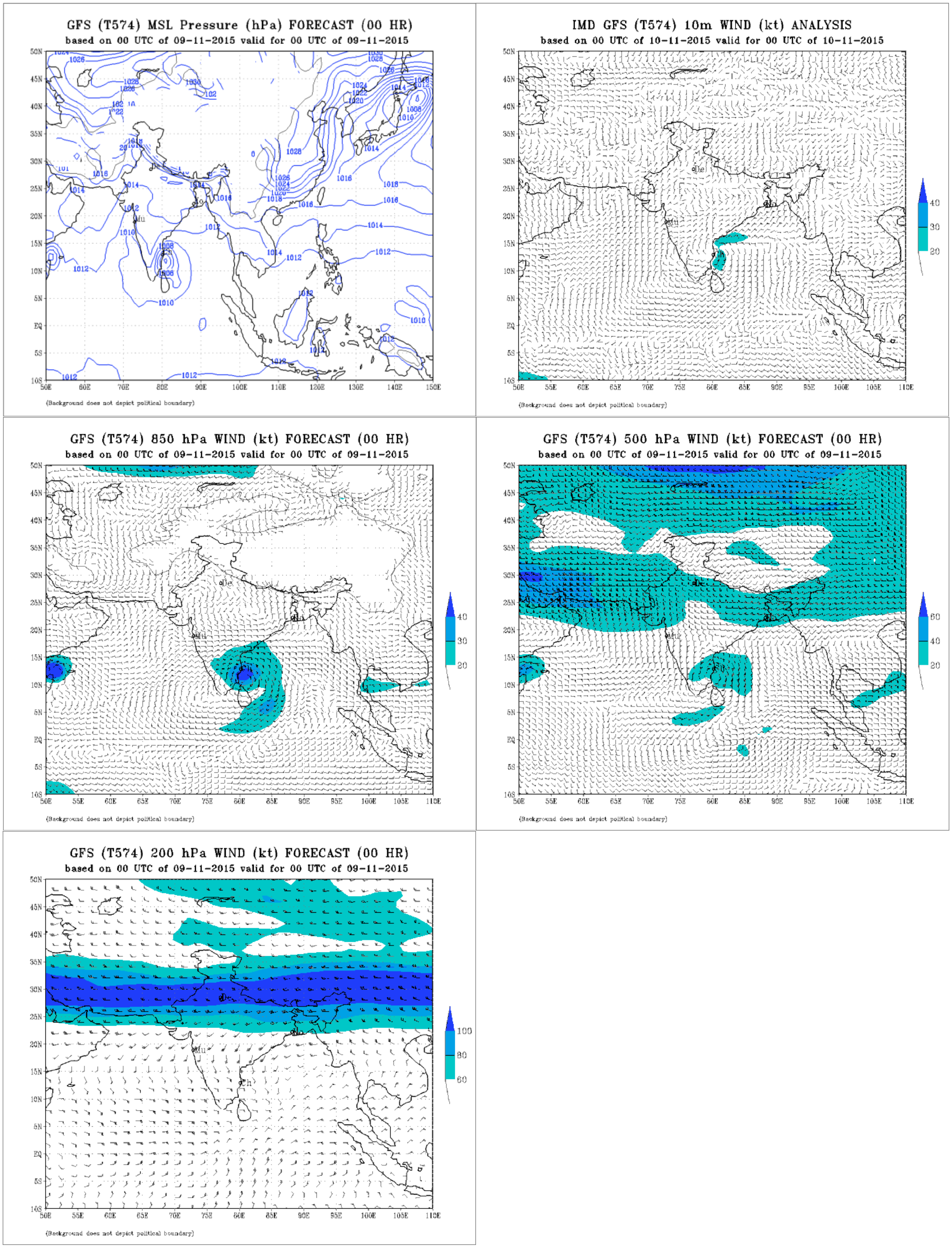


Fig.2.4.11(f) IMD GFS analysis of MSLP, 10m wind and winds at 850, 500 & 200 hPa levels based on 0000 UTC of 10th November.

2.4.8 Realized Weather:

2.4.8.1 Rainfall:

Rainfall associated with the system is depicted in Fig.2.4.12 based on IMD-NCMRWF GPM merged gauge rainfall data

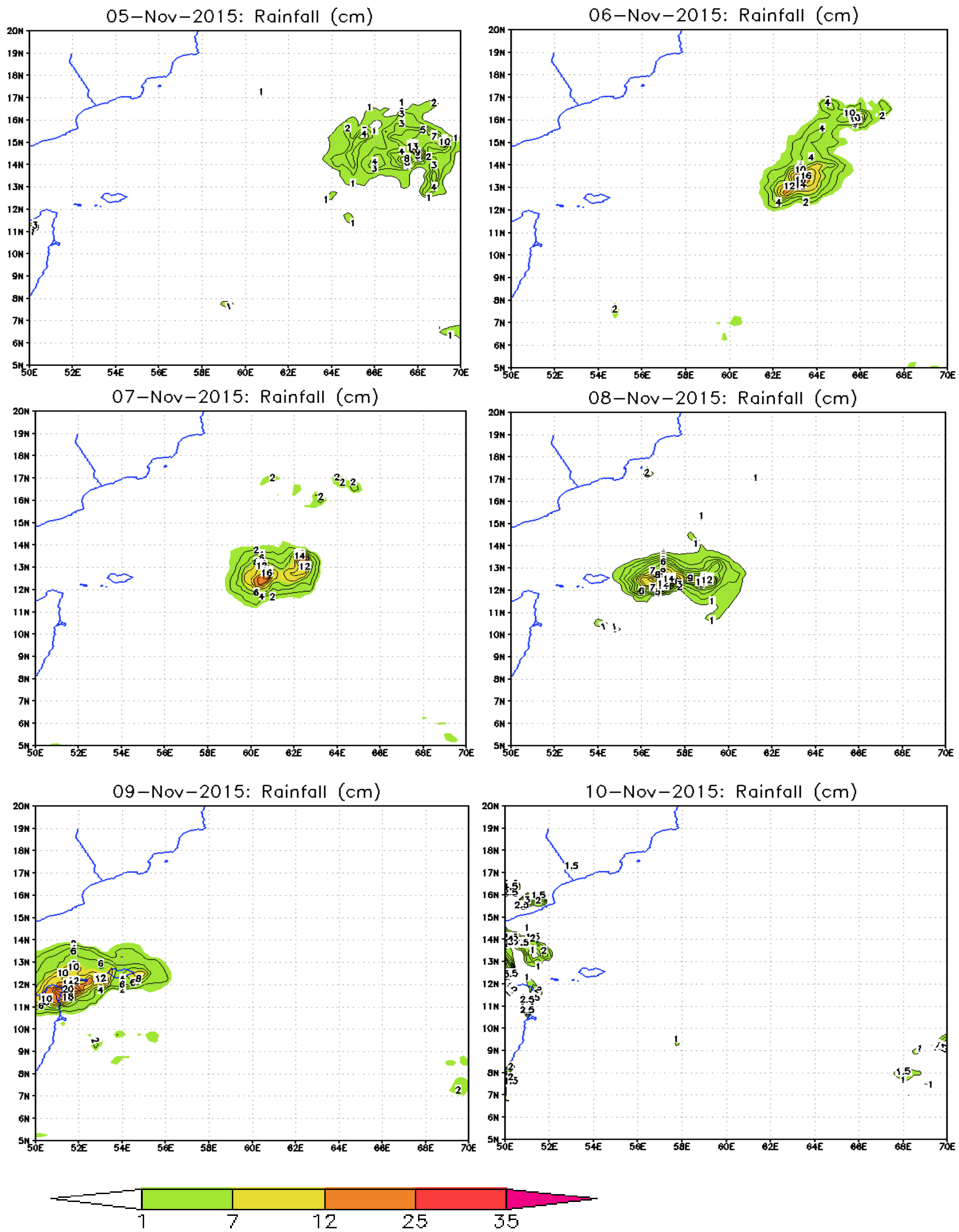


Fig.2.4.12 IMD-NCMRWF GPM-gauge merged 24-hr rainfall as on 0300 UTC of the date indicated in each plot for the period 05-10 November 2015

During the initial stage of formation of the system, on 5th November, rainfall belt was east-west oriented and the rainfall maximum was observed to the northeast of the system centre. Similar pattern was observed on 6th November with extension of rainfall belt from southwest to northeast. Subsequently, with the organisation of the system, convection became more and more organised and rainfall was symmetric about the centre on 7th and 8th November. However, gradually the rainfall maximum shifted to the southwest with gradual weakening of the system from 8th and west-southwestwards movement, the rainfall belt was elongated towards west-southwest from east-northeast. As a result the northern tip of Somalia experienced haevy rainfall on 9th. The rainfall almost decreased on 9th and 10th due to rapid weakening of the system.

2.4.9 Damage due to ESCS Megh

As per media and press report, ESCS Megh caused extensive devastation, killing at least eighteen people and injuring dozens of others. More than 500 houses were completely destroyed and another 3,000 were damaged. In addition, hundreds of fishing boats were damaged and more than 3,000 families were displaced. The typical damage photographs over Socotra Island are presented in fig2.4.13.

Yemini Island, Socotra lashed by high winds and torrential rains

Dragon's blood tree is seen on the ground after Megh hits Socotra Island

Fig. 2.4.13:Typical damage photographs over in asssociation with ESCS Megh over Socotra Island

CHAPTER-III

CONTRIBUTED PAPERS *ON* CYCLONES & DEPRESSION
Abstract of Papers Published in Journal, *'MAUSAM'*

1. **Spatial verification of rainfall forecasts for very severe cyclonic storm 'Phailin'**

SAJI MOHANDAS and HARVIR SINGH NCMRWF,
A-50, Sector-62, Noida, U. P. – 201 309, India
e mail : saji.md@nic.in

ABSTRACT:
The current study demonstrates the utilisation of a tool for the comprehensive evaluation of model forecasts using both traditional and spatial diagnostic techniques. The fundamental idea is to provide additional and meaningful insight into the model weaknesses and strengths in terms of underlying physical processes especially for very high resolution models and observations. The traditional scores also suffer from the so called "double penalty" issue and hence alone cannot provide a measure of spatial and temporal match between the forecast and observed rainfall patterns. Method for Object-based Diagnostics Evaluation is a spatial verification technique in the category of displacement methods while wavelet analysis comes into filtering type of spatial verification. Former is a features based verification technique while the latter is based on scale-separation principle. The case of Very Severe Tropical Cyclone 'Phailin' is taken up for the study and the rainfall forecasts from Global Forecast System and Unified Model run at National Centre for Medium Range Weather Forecasting are verified against gridded satellite-cum-raingauge-merged rainfall analysis. The traditional verification scores were computed using categorical and continuous measures and the spatial verification scores were computed against various thresholds. The results are presented to summarise the overall performance of both the global models with respect to the rainfall prediction.

Key words: Model evaluation tool, Categorical verification scores, Object-based diagnostics, Intensity-scale analysis.

2. Verification of forecasts of IMD NWP based cyclone prediction system (CPS) for cyclones over the north Indian seas during 2013

S. D. KOTAL, SUMIT KUMAR BHATTACHARYA, S. K. ROY BHOWMIK and P. K. KUNDU*

India Meteorological Department, Lodi Road, New Delhi – 110 003, India *Jadavpur University, Department of Mathematics, Kolkata – 700 032, India

e mail : sdkotal.imd@gmail.com

ABSTRACT:

As a part of our effort to meet the specific requirement of the operational forecaster, an objective NWP based Cyclone Prediction System (CPS) was developed and implemented for the operational cyclone forecasting work. The method comprises of five forecast components, namely (a) Cyclone Genesis Potential Parameter (GPP), (b) Multi-Model Ensemble (MME) technique for cyclone track prediction, (c) Cyclone intensity prediction, (d) Rapid intensification and (e) Predicting decaying intensity after the landfall. GPP is derived based on dynamical and thermo dynamical parameters from the model output of IMD operational Global Forecast System. The MME technique for the cyclone track prediction is based on multiple linear regression technique. A Statistical Cyclone Intensity Prediction (SCIP) model for predicting 12 hourly cyclone intensity (up to 72 hours) is developed applying multiple linear regression technique. For forecast of inland wind after the landfall of a cyclone, an empirical technique is developed. This paper describes the development strategy of the CPS and performance skill of the system during 2013 for seven cyclonic disturbances. The performance evaluation shows that the GPP analysis at early stages of development of a low pressure system was able to indicate the potential of the system for further intensification. The 12 hourly track forecast by MME (with error 68 km at 12 hr to 187 km at 120 hr), and intensity forecast by SCIP model (with error 5.9 kt at 12 hr to 19.8 kt at 72 hr) are found to be consistent and very useful to the operational forecasters. The probabilistic rapid intensification forecasts are found to be skillful compared to climatology. The error statistics (11 kt at 6 hr to 6 kt at 24 hr) of the decay model shows that the model could predict the decaying intensity after landfall with reasonable success. The performance statistics demonstrates the potential of the CPS for improving operational cyclone forecast service over the north Indian Seas.

Key words: Cyclone genesis potential parameter (GPP), Multi-model ensemble (MME) technique, Cyclone track prediction, Cyclone intensity prediction, Rapid intensification, Decay, Forecast verification.

3. Tropical cyclone forecast from NCMRWF global ensemble forecast system, verification and bias correction

ANUMEHA DUBE, RAGHAVENDRA ASHRIT, AMIT ASHISH, GOPAL IYENGAR and E. N. RAJAGOPAL NCMRWF,
MoES, A-50, Sector 62, NOIDA – 201 309, India
e mail : anumeha.dube@nic.in

ABSTRACT:
The North Indian Ocean is one of the world's worst affected areas by tropical cyclones. It is because of its vast coastline and high population density in the coastal areas that the damage to life and property caused by a landfalling tropical cyclone is huge. Therefore, timely prediction of the cyclone track, landfall location and time is of critical importance for this region. In the present study a comparison is made between the relative skills of a deterministic model NGFS (NCMRWF Global Forecast System) and an ensemble prediction system (EPS) NGEFS (NCMWRF Global Ensemble Forecast System) in predicting the tropical cyclone track. Four cases of recent cyclones, i.e., Phailin (9-12 October 2013), Helen (19-23 November, 2013), Lehar (23-28 November, 2013) and Madi (6-12 December, 2013) are considered for this comparison. Except of Helen which was a Severe Cyclonic Storm (SCS), all the above cyclones were in the category of Very Severe Cyclonic Storms (VSCS). Further an attempt is made to correct the systematic biases in NGEFS model by using the method of moment adjustment. A comparison of the performance of the models is made on the basis of along track, cross track and direct position errors obtained from the forecast tracks from the three models and the IMD best track data. It is seen that for a cyclone like Phailin which did not show any sudden changes in the track the mean of NGEFS shows a lower track error as compared to NGFS and the bias corrected output from NGEFS shows a further improvement in the TC track forecast. However, in the case of Madi which showed a sudden change in the direction NGEFS showed a better forecast before the direction change as compared to both NGFS and the bias corrected NGEFS. But after the change in the direction NGEFS with bias correction is seen to be performing better than NGEFS and NGFS. On an average for the four cyclone cases of 2013 it is seen that the bias correction leads to an improvement of about 17% in the initial position error as compared to raw ensemble track forecast and about 38% when compared with the deterministic model. In the day 5 forecasts the improvement in the bias corrected ensemble forecast as compared to NGEFS and NGFS are 24% and 17% respectively.

Key words: Tropical cyclone, Phailin, Helen, Lehar, Madi.

4. Evaluation of short range forecast for tropical cyclones over north Indian Ocean using TIGGE data

Y. V. RAMA RAO, K. NAGARATNA*, D. JOARDAR, ARUN SHARMA and ANIL KUMAR India Meteorological Department, New Delhi – 110 003, India *Meteorological Centre, IMD, Hyderabad – 506 001, India

e mail : yvramarao.imd@gmail.com

ABSTRACT: Forecasts of tropical cyclone (TC) tracks from three global models ECMWF, NCEP and UKMO deterministic and ensemble forecasts based on TIGGE TC data during the years 2010 to 2014 were evaluated to study the capability of these models for track forecast guidance over the North Indian Ocean (NIO). To measure the performance of the global model forecasts, a series of statistical evaluations of track forecasts including the initial position errors, mean and cross track and along track errors bias up to 72 hr were carried out. The deterministic track forecast errors of NCEP and ECMWF models at 72 hr were 232 and 272 km, respectively. However the ensemble means track forecasts errors of NCEP, ECMWF, UKMO models at 72 hr were 252, 322, and 374 km respectively. It shows NCEP models had less error than ECMWF and UKMO. Compared to India Meteorological Department (IMD) operational track forecast errors, NCEP deterministic and ensemble forecasts have shown skills within ±15% and ECMWF deterministic forecasts have shown 4 to -19% from 24 to 72 hr forecast range. The ECMWF and UKMO ensemble forecasts showed large negative skills compared to IMD operational forecast track errors. However, IMD operational forecasts showed better skill upto 12 hr compared to all the models. In all the models it shows that NCEP deterministic and ensemble forecasts have better skills compared to ECMWF and UKMO models over NIO. Independent study of each basin Bay of Bengal and Arabian Sea has shown that NCEP deterministic and ensemble track forecasts have shown better skills over both the basins compared to ECMWF and UKMO models. ECMWF forecasts have shown slight better skills over Bay of Bengal compared to Arabian Sea. The UKMO ensemble forecasts show large negative skill over both Bay of Bengal and Arabian Sea.

Key words: Tropical cyclone, North Indian ocean, Track, Direct position error, Forecast skills.

CHAPTER-IV
COORDINATED TECHNICAL PLAN (CTP): 2016-2019

4.1. INTRODUCTION AND BACKGROUND

Hydro-meteorological disasters account for approximately 70-80% of disaster losses in the world. Among them, tropical cyclone associated disasters remain to be serious threats to people in both developed and developing countries in the tropical cyclone prone regions. This is obviously true for the North Indian Ocean region, where the devastating disasters repeated during the past decades proved that this region is extremely vulnerable to the tropical cyclone risks.

WMO/ESCAP Panel on Tropical Cyclones for the Bay of Bengal and Arabian Sea has been exerting its effort to mitigate the impact of tropical cyclones in this region since its inauguration in 1973. The Panel's activities are fundamental contribution to improving the regional and national resilience against the tropical cyclone threats.

In view of the growing demand for further mitigation of tropical cyclone disasters in this region as well as enhancement of visibility of its activities, the CTP (2009-2011) was developed by the PTC Policy Working Group chaired by Dr. Qamar-uz-Zaman Chaudhry, Secretary of PTC and adopted by the PTC during its 36th Session (Muscat, Oman, 2-6 March, 2009)..

The present CTP (2016-2019) is an updated version of previous Coordinate Technical Plansand has also taken into consideaton the WMO Strategic Plan 2016-2019 and the Strategic Plan for the Enhancement of National Meteorological and Hydrological Services in Regional Association II (2012-2015).

4.1.1 Panel Region

Currently, the Panel is composed of nine Members; Bangladesh, India, Maldives, Myanmar, Oman, Pakistan, Sri Lanka, Thailand and Yemen.

The Panel region covers a vast expanse of the North Indian Ocean and contains a large and diverse range of ecosystems, including deserts, forests, rivers, lakes and seas. The desert extends from Oman into Pakistan and northwest India. Compared to other WMO tropical cyclone regions, this region includes the highest mountains, the rainiest areas and the driest deserts, with their associated variation in culture and biodiversity. Over the long period of human occupation in the region, exploitation of natural resources, urbanization, industrialization and economic development have led to land degradation and environmental pollution. Climate change and climate variations also represent present and future stress.

Tropical cyclone warning services of the Members vary in duties, size and status of advancement, geography and state of development. Therefore, they are highly differentiated in capabilities and vulnerabilities. Some Members have very advanced facilities while others have limited budgets; shortage of observation instruments, spare parts, consumables; lack of calibration, data collection, processing and communication facilities; insufficient qualified staff; and old technology.

4.1.2. Vision and mission of the Panel

4.1.2.1. Vision of the Panel

To promote and coordinate the planning and implementation of the multi hazard early warning based Disaster Risk Reduction system to attain sustainable development measures through minimizingloss and damage caused by tropical cyclones and associated meteorological, hydrological and other ocean hazards in the Bay of Bengal and the Arabian Sea.

4.1.2.2. Mission of the Panel

a. *To review regularly the progress made in the various fields.*
b. *To recommend measures to improve the multi-hazard early warning systems in the Bay of Bengal and the Arabian Sea, including necessary training and research, with regard to meteorological, hydrological and other ocean hazards such as storm surges and tsunamis*
c. *To recommend measures to improve information dissemination system to ensure timely provision of warnings for community preparedness and disaster risk management.*
d. *To advise on possible sources of financial and technical support for such measures.*
e. *To coordinate the activities among the Panel Members, including all other activities carried out as part of or in conjunction with the WMO and regional tropical cyclone programmes.*
f. *To encourage and carry out capacity building.*

4.1.3 Priorities of the Panel

The Panel agreed that the following are priority issues:

a. Maintenance of existing system and further development of land, Ocean and atmosphere observing and telecommunications systems and data processing facilities for better information sharing;
b. Natural disaster reduction, mitigation and prevention through the implementation of improved detection, prediction and warning systems of tropical cyclones, depressions and associated storm-surge, high waves, flash/urban floods, tsunamisetc.;
c. Implementation of CTP to provide better services to the public, governments and users, through improved infrastructure and by modern technology in a user-friendly manner;
d. Enhancement of capacity building and technology transfer for early warning dissemination and response at the national and community levelsto bridge the gap between the Members through bilateral and multilateral arrangements;
e. Enhancement of the collaboration and cooperation among the Members and RSMC New Delhi by exchange of information and knowledge and research studies related to tropical cyclone including numerical modeling and climate change impacts. Member countries to encourage and promote research on Multi hazards associated with tropical cyclones, tsunamis and other marine hazards;
f. Encouragement to improve hydrological forecasting and warning services for flood prone areas;
g. Encouragement to plan and manage water resources, including assessment of surface and ground water resources in relation to tropical cyclones;
h. Improvement of the operational linkages between hydrological and meteorological services and disaster management agencies with the aim to minimize the impacts of natural disasters;
i. Facilitation of tropical cyclone disaster risk assessment at the country level, especially along the coast, delta, and urban areas where risks are the highest to reach sustainable development goals

j. Increase of tropical cyclone risk awareness at the community level through awareness events, school education, trainings, and drills where technical knowledge could be properly supplied and adopted by authorities;
k. Strengthening information exchange with various disaster-related information systems in the region;
l. Strengthening partnerships with relevant international and regional bodies, such as UN-ISDR, UNDP, UNESCO/IOC, UNEP, ESCWA,ASEAN, SAARC, IFRC, ADRC, ADPC, ICHARM, JICA, KOICA, TICA, USAID, ADB, ICAO, RIMES, BIMSTEC and WB;
m. Enhanced public & private partnership including industries, non-governmental organisations (NGOs) etc. for awareness, feedback and information dissemination etc. aiming to disaster risk reduction (DRR);
n. Enhancement of resource mobilization activities for implementation of CTP.

4.1.4 Challenges and Opportunities

Panel is facing challenges and opportunities that have been raised in recent years in its implementation of the activities to fulfill its vision, such as rapid changes in technology, globalization, commercialization, urbanization, and emerging scientific research results. This section identifies in broad terms the challenges and opportunities of which the Panel Members could take advantage through a strategic regional approach.

4.1.4.1 Meteorology

4.1.4.1.1. Observation systems

Observation systems are fundamental to the operations of National Meteorological and Hydrological Services (NMHSs). Standardization of observation ensures that data collected by each country are compatible with other countries. This includes accuracy, instrument response times and other characteristics of instruments, frequency of observations, exposure, network densities and other related matters.

The existing gaps in the observational data coverage of the Panel region continues to be due to the deficiencies in the operations of both land, Ocean &atmosphere observing systems and telecommunication networks, high cost and therefore the lack of consumables and spare parts.

New types of earth observing satellites including meteorological satellites which are useful to weather monitoring, forecasting, and research have been launched from time to time. However, no single receiving system is capable of receiving and processing the data from all these satellites. This poses difficulty to some Members that may not afford to have more than one satellite receiver. It would be useful if imageries and data from different satellites can be put under and distributed through one or two low cost distribution channels.

4.1.4.1.2. Telecommunication

The collection of observational data within each country and the exchange of observational data and processed information between countries are made through the WMO Information System (WIS). The WIS includes the GTS for time-critical and operation-critical data exchange, and the data discovery, access and retrieval service through the Internet.

The GTS part includes the national meteorological telecommunication networks (NMTNs) and the regional meteorological telecommunication networks (RMTNs), respectively. The NMTNs are implemented and operated by each country according to both the telecommunication services available and the financial and technical capacities of each country.

4.1.4.1.3. Data-processing and forecasting systems

While there had been considerable improvements in the infrastructure and models in some Global Data Processing and Forecasting System (GDPFS) centers of the Region, there are still large deficiencies in the capabilities of some Members in theirforecasting function, i.e., the production of forecasts and warnings. Some of the data processing systems of NMHSs have not been automated and the Members concerned were not able to derive full benefits from the technological advances that have taken place in the recent past. Some GDPFS centers in the Region still plot stations and produce weather charts manually.

As regards the generation and dissemination of the GDPFS products, Regional Specialized Meteorological Centre (RSMC) New Delhi produces a large number of products on a daily basis. The availability on the Internet of high-quality products from advanced high-resolution NWP systems operated by major GDPFS centers within and outside the Region has opened up new opportunities for NMHSs to enhance their capability in providing weather forecast service to their respective users.

4.1.4.2. Hydrology and Water resources

Freshwater is a natural resource vital to the survival of all living things; however, it is limited. The sources of freshwater are river basins, groundwater reserves, lakes and manmade reservoirs. These are increasingly under pressure to meet increased domestic needs as well as demands from agriculture, industry and other human activities.

Weather is the most important factor in water availability as it determines the timing and the location of precipitation and the amount lost to evaporation. Some arid countries in the region like Oman, Yemen, Southern Pakistan and Northwestern India have such low precipitation (as little as a few millimeters per year) and high evaporation, that only a small amount of freshwater can be captured for human use. By contrast, some countries receive abundant rainfall each year (thousands of millimeters). Seasonality is particularly pronounced throughout the region and, in most cases, plays a major role in water availability; those countries which receive high rainfall - Bangladesh and India for example - are inundated with rainfall during the monsoon season, but lack rainfall the rest of the year.

This seasonality problem can be tackled by preventing the precipitation during the wet season from running off into the sea. The traditional method of rain harvesting, that is, retaining water through construction of ponds/lakes etc in individual villages or towns could ensure the optimum use of precipitation. Many demonstration projects have established that with proper storage techniques, rainfall during a season could be utilized throughout the year for agriculture and other human activities. It is such mini projects, rather than big dams, that are most cost-effective in conserving fresh water resources.

The decline of hydrological networks in the region is a challenge at a time when more high quality hydrological data are required, often in near real time. Hydrological networks need to be improved together with the capacity of Hydrological Services to provide relevant information to a variety of users of hydrological data. In this respect, the need for improving forecasting systems particularly to predict floods and droughts that could lead to disasters is a high priority in the region. The management of international rivers in the region is a most challenging problem as well. In the context of integrated water resources management, the joint management of river basins opens a window of opportunity for transnational collaboration in hydrology.

The potential extension of several HYCOS projects into the region are expected to foster this process and contribute to the capacity building of National Hydrological Services as well as integrated water resources management on the basis of timely, reliable hydrological data. Especially for prediction and forecasting of extreme events, the data collection and forecasting capacities of the meteorological and hydrological branches of national Services need to be integrated to provide the results required by the general public.

Likewise, the introduction of rational water resources assessment methods, promoted by WMO and the United Nations Educational, Scientific and Cultural Organization (UNESCO), are expected to enhance the capacity of National Hydrological Services in the region to act as service providers for planning, decision-making and implementation of water resources projects. A crucial issue for much needed regional collaboration between national Hydrological Services is the free exchange of hydrological data and information which has been documented in Resolution 25 of the Thirteenth Congress of WMO.

4.1.4.3 Disaster Risk Reduction

The Panel region is one of the most disaster prone regions in the world. It has a very high frequency of disaster events and suffers from immense damage due to various types of disaster such as tropical cyclones, storm surges, floods, landslides, drought, earthquakes, volcanic eruptions, tsunamis, etc.

A large percentage of these disasters have occurred in many countries of the Region. A rapid urbanization, high population increase rates, and high population densities without reducing the poverty levels led their societies to be with high vulnerability to disasters, resulting in heavy loss of life and property damage. The Disaster Risk Reduction component of the CTP will aim at reducing tropical cyclone disaster risks at the community level by enhancing the local and institutional capacities to cope with the risks.

4.4.3.1. Tropical cyclone related disaster risks

In the Bay of Bengal, tropical cyclones usually form over the southern end then move either towards the east coast of India, Myanmar or to Bangladesh and a few of them emerge into Arabian Sea after crossing the Indian Peninsula and Sri Lanka. A few tropical cyclones form in the Arabian Sea and move to the north affecting the western part of India, southern Pakistan, Yemen and Oman. These tropical cyclones can generate very heavy rainfall and cause severe flooding and landslides, high wind and waves, and are often accompanied by devastating storm surges which are the most common risk factor to the tropical cyclone deaths. Quantification of associated risks might help to plan appropriate DRR actions.

4.4.3.2. Regional technical coordination on tropical cyclones

Regional cooperation and coordination in disaster prevention and mitigation among the Members are gaining importance in the region. India Meteorological Department was designated by WMO a Regional Specialized Meteorological Centre (RSMC) to monitor and forecast the track and intensity of all tropical cyclones in this region, to provide the track and intensity information to the international community, and to provide real-time advisory information and guidance to NMSs in the region. Mechanism may be set up to foster tele conference (audio/video) for consultation among members and RSMC, New Delhi.

4.1.4.3.3. Inter Regional Co-operation on Tropical Cyclones

Real time exchange of information, data and products between RSMC, New Delhi and RSMC, Tokyo for monitoring and prediction of tropical cyclones to be institutionalised. WMO may co-ordinate this co-operation. The archived informations, data and products also to be exchanged for R& D purposes.

4.1.4.3.4. Risk assessment and management

Accurate and timely tropical cyclone forecast and warning issued by the NMHSs is crucial information to reduce risks. The challenge is that such information needs to be reached to the communities at risk for prompt actions. This is quite a challenge, especially rural areas in developing countries where the communication system is limited. Even reached on time, false information or technical information lacking clear directions and guidance for a specific location may mislead response to the warning and hinder people's willingness to take actions for the next events. It is vital to understand the perception of individual and collective behaviors when receiving the warning. Another important issue is whether people have a safe place when responding to the warning. Without such places, people would be ended up facing the risks. Whether they could move quickly to the safe place is additional issue, in particular, for infants, small children, the elderly, and the handicapped.

4.1.4.3.5. Linkages with International framework initiatives

Activities of the Panel on Tropical Cyclones may be linked appropriately with the important initiatives such as the International Network for Multi-Hazard Early Warning Systems (IN-MHEWS) established at the Third United Nations Conference on Disaster Risk Reduction in March 2015, and the Climate Risk Early Warning System (CREWS) launched at the Conference of the Parties of the United Nations Framework for Climate Change in December 2015. In this regard, WMO and ESCAP may extend institutional support the Panel on Tropical Cyclones. Taking the opportunities of the Asian Ministerial Conference on Disaster Risk Reduction in November 2016, ESCAP and WMO may organize a joint side event of the Panel on Tropical Cyclones, the Typhoon Committee, and the Tropical Cyclone Committee to shape the regional component of IN-MHEWS in Asia-Pacific under the Global Framework of Climate Service (GFCS).

4.1.4.4. CapacityBuilding

In considering the rapid changes in technology and the social, political and economic circumstances in addition to the global environmental issues, Members need to respond to these challenges in such a way as to enable them to properly manage their meteorological and hydrological services, and to have qualified and trained manpower and adequate facilities. Therefore, proper management, continuing training and development are important for the advancement of those services.

RSMC New Delhi, Indian National Centre for Ocean Information Services (INCOIS), Hyderabad and academic institutions to supportthe plans and requirements related to capacity building and transfer of technology in close cooperation with the Members.

Capacity building is to be underpinned by infrastructure and human resource development through training and technology transfer in the areas of:

a. Forecasting of tropical cyclone intensity and track, and associated storm surge, inland flooding and coastal inundation
b. Observing and processing data and interpretation of outputs from regional centres;
c. Information and communication technology (ICT);
d. Equipment maintenance;
e. Provision of weather services for the public, including service-oriented media/communication skills;
f. Provision of weather services for aviation and shipping, including marketing of services and liaison with clients;
g. Provision of climate information services;
h. Application of NWP products;
i. Nowcasting of severe weather; and
j. High level and middle management skills.
k. Climate change impacts on tropical cyclones and associated phenomenon
l. Maintenance of competency standards

Training through fellowships, seminars and workshops with assistance from outside the region needs to be also intensified.

4.1.5 International and regional projects relevant to the Panel's activities

The following international/ regional projects with significant potential benefits to Members especially the developing ones are worth pursuing:

4.1.5.1. Early Warning System for Tsunamis

After the devastating tsunami which affected most of the countries of the Panel towards the end of December in 2004, there has been an urgent need to establish an Early Warning System for the Panel region. In this connection, WMO, along with other International Organizations, worked towards bringing the countries of the region to work together in identifying an ideal mechanism that will support an Early Warning System for the region. The Panel should take advantage of this situation and participate in all the forums that are called upon by WMO in this regard. It is important that the Panel collaborates with the adjacent regions in establishing this project. It should then draw up a plan for implementation having all the Members participate.

4.1.5.2 Storm Surge Watch Scheme

In view of the fact that storm surges associated to the recent tropical cyclones Sidr and Nargis in the Bay of Bengal, which caused widespread flooding in the exposed coasts of Bangladesh and Myanmar, were the major cause of devastation and loss of lives in the most populous and low-lying areas of these countries, the WMO Executive Council, at its 60th session in 2008 (EC-LX), addressed the need for the provision of storm surge guidance information to the WMO Members exposed to these risks as a matter of priority.

The Council therefore agreed that a storm surge scheme attached to the tropical cyclone advisory arrangements would help to increase advisory lead-time and thus contribute to saving lives and properties, and would be the first step towards a comprehensive and integrated marine multi-hazard forecasting and warning system for improved coastal risk management. It appealed to all the regional tropical cyclone bodies to develop Storm Surge Watch Scheme (SSWS) that will make available to WMO Members concerned the storm-surge advisories including daily marine processed data and information they require for real-time uses.

In the Panel region, efforts have to be continued under CTP for attachment training on country specific advanced storm surge forecasting and inundation modelling.

4.1.5.3 Hindu Kush-Himalayan Hydrological Cycle Observing System (HKH-HYCOS) Phase II project

The Hindu Kush-Himalayan Hydrological Cycle Observing System (HKH-HYCOS) Phase II project, which was funded by the government of Finland, was successfully completed on December 31, 2015. HKH-HYCOS Phase III project proposal has been prepared and is being circulated to potential donors.

4.1.5.4. Mekong-HCOS project

The Mekong-HCOS project was successfully completed on 30 November 2012. The project was financially supported by the AgenceFrancaise de Developpement (AFD). AFD is further supporting additional efforts with the Mekong River Commission on extending the MRC-HYCOS network and improving its sustainability, as well as improving data usage based on statistical hydrological analyses.

4.1.5.5. WMO's Severe Weather Forecasting Demonstration Project (SWFDP)

At present, several SWFDP regional subprojects are in progress including in Southern Africa, South Pacific, Eastern Africa, Southeast Asia, Bay of Bengal, and Central Asia. One of the main objectives of SWFDP is to improve forecasting and warning services for hazardous weather in participating countries through efficient use of the'Cascading forecasting process' of GDPFS centres (i.e. Global to Regional to National) and by making best use of the available NWP products and satellite information, and through improved coordination of NMHSs with targeted users including disaster management and civil protection authorities and media. The development planning for SWFDP-Bay of Bengal was initiated in 2012 with participation of six countriesnamely: Bangladesh, India, Maldives, Myanmar and Sri Lanka and Thailand. Since then a steady progress has been made towards SWFDP-Bay of Bengal development and implementation.The contributing global centres are: IMD, JMA, UKMO, NOAA/NCEP and ECMWF. As one of the contributing global centres, IMD is also supported by National Centre for Medium Range Weather Forecasting (NCMRWF) and Indian National Centre for Ocean Information Services (INCOIS) for NWP and marine related products respectively. The password-protected subproject website has been developed by RSMC New Delhi in 2015.Based on Members' interest in SWFDP and considering potential benefits which it could bring to the NMHSs in South Asia, the subproject has been extended to three more countries in the region including Bhutan, Nepal and Pakistan. Most of the Panel Members are also participating countries of SWFDP-Bay of Bengal. The pilot phase commenced on 2nd May, 2016 with issue of regional severe weather guidance by RSMC, New Delhi.

4.1.5.6. Flash Flood Guidance System with Global Coverage (FFGS)

In collaboration with NOAA-National Weather Service, the US Hydrologic Research Centre, WMO and USAID/OFDA, this project is currently being implemented in the MekongRiver Basin in collaboration with MRC. Other areas under development for the implementation of the project are south Asia, southern Africa and near/middle East. The reference project had been implemented over the past years in Central America. The success of the project there was the basis to expand it globally where feasible. The core of the project is to provide flash flood guidance (not forecasting!) to disaster managers based on real-time satellite-derived precipitation estimates merged with resolution GIS and hydraulic conditions of rivers that trigger an alert once "bankful" flow conditions are to be expected based on the precipitation estimate for a given time under prevailing ground and hydraulic conditions. The first Steering Committee meeting held at New Delhi recommended to link flash flood guidance provided by regional flash flood guidance centres for south Asia with SWFDP-BOB.

4.1.5.7. WMO Programme for the Least Developed Countries (LDCs)

This Programme was established by the Fourteenth Meteorological Congress in May 2003 to contribute efficiently and in a timely manner to the social and economic development efforts of LDCs through the enhancement of the capacities and capabilities of their NMHSs. A number of activities are being carried out in support of NMHSs of most of the 50 LDCs under the WMO Programme for LDCs and through the other WMO scientific and technical programmes. This includes the development and implementation of Internet connection projects in LDCs; provision of fellowships; supporting the participation of experts from LDCs in WMO meetings; carrying out special advocacy and project-formulation activities; and the organization of innovative capacity-building initiatives including workshops on good practices in the beneficial and effective use of weather-, climate-, and water-related services in sustainable socio-economic development.

Planned activities include the following:

- Development and organization of demonstration/pilot projects on the contribution of meteorological and hydrological and related environmental information, products and services to the sustainable development of the LDCs and Small Island Developing States (SIDS), especially in poverty alleviation, disaster risk reduction, environmental protection, food security, health, energy and water resources management;
- Organization of capacity-building activities for senior- and middle-level staff of LDC NMHSs, particularly in leadership, management, resource mobilization, strategic planning, marketing and communication;
- Preparation and implementation of development and modernization plans of NMHSs of LDCs and SIDS, including projects that are of relevance to, and consistent with, national development strategies and programmes and of high impact value to the relevant commitments enshrined in the Brussels Programme of Action for the LDCs;
- Promoting the awareness of policy- and decision-makers and other stakeholders of the socio-economic benefits of weather-, climate- and water-related services;
- Preparation of guidelines for promoting the contributions of NMHSs and WMO towards the attainment of internationally agreed development goals including those contained in the Millennium Declaration.

4.1.6. WMO Programmes and other Regional/International Programmes in support of the Panel Members

4.1.6.1. WMO Programmes

The major WMO Programmes concerned are the World Weather Watch (WWW), the World Climate Programme (WCP), PWS (Public Weather Service), DPFS (Data-Processing and forecasting Service), MMO (Marine Meteorology and Ocean Affairs), DRR (DisasterRiskreduction), SP (Satellite), AEM (Aeronautical Meteorology), HWR (Hydrology and Water Resources), RAP (Regional Office Asia/South-West Pacific), ETR (Education and

Training), WWRP (World Weather Research Programme), Global Framework for Climate Services (GFCS).

4.1.6.2. Regional and international programmes

Programmes of the following organizations are of interest:

ESCAP; the ASEAN Subcommittee on Meteorology and Geophysics (ASCMG); the Interstate Council on Hydrometeorology of the Countries of the Commonwealth of Independent States (ICH CIS); the Coordinating Committee on Hydrometeorology and Pollution Monitoring of the Caspian Sea (CASPCOM); the UNESCO Intergovernmental Oceanographic Commission (IOC); the United Nations Environment Programme (UNEP); UNDP; the Global Environment Facility (GEF); the Economic Cooperation Organization (ECO); the Economic and Social Commission for Western Asia (ESCWA); the South Asia Association for Regional Cooperation (SAARC); the League of Arab States (LAS); the Permanent Meteorological Committee; (BIMSTEC);Regional Integrated Multi- hazard Early Warning System (RIMES); (ADPC) and the Regional Organization for the Protection of the Marine Environment (ROPME).

4.1.7. Agreements and conventions

Members are encouraged to undertake national responsibilities or contribute to national obligations under many regional and international agreements and conventions. Some of the most important ones are the WMO Convention; Agenda 21 adopted at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992; the 1994 Global Conference which adopted the Barbados Programme of Action for Sustainable Development of Small Island Developing States; Resolution 40 of Twelfth Congress (1995) on the policy and practice for the exchange of meteorological and related data and products including guidelines on relationships in commercial meteorological activities; Resolution 25 of Thirteenth Congress (1999) on the exchange of hydrological data and products; the Geneva Declaration of Thirteenth Congress (1999); Millennium Development Goals (2000); Sustainable Development Goals 2015-2030; Hyogo Framework for Action 2005-2015; Sendai Framework for Disaster Risk reduction (2015-2030); the United Nations Framework Convention on Climate Change (UNFCCC); the United Nations Convention to Combat Desertification (UNCCD); the Convention of the International Civil Aviation Organization (ICAO); the Convention of the International Maritime Organization (IMO); the International Convention for the Safety of Life at Sea (SOLAS); and the Convention on the Protection of the Ozone Layer and most recent and important Paris agreement on Climate Change 2015.

There are also a number of United Nations programmes and agencies having activities related specifically to meteorology, climate or hydrology or providing financial support to countries. These include UNEP, the United Nations Development Programme (UNDP), the Food and Agriculture Organization (FAO) of the United Nations and others.

4.2. DEVELOPMENT OF COORDINATED TECHNICAL PLAN

4.2.1 Purpose of Coordinated Technical Plan

Coordinated Technical Plan aims to promote and co-ordinate the planning and implementation of the measures required to minimize damages caused by tropical cyclones and associated floods and storm surges in the Bay of Bengal and the Arabian Sea. It is expected to establishan effective integrated regional early warning system for those hazards in the region covering all the five components; meteorology, hydrology, disaster prevention and preparedness, training and research.

Specific purposes of the Coordinated Technical Plan are:

(a) To develop an understanding among the Panel Members on the priorities and objectives for their individual development and for the overall development of the Panel region through cooperation; and to guide the implementation of Panel's programmes and activities for achieving these objectives;
(b) To develop and provide access to appropriate databases, resources and expertise to produce appropriate advice and products required for forecasting and warning services to the private and public sectors as well as to the decision makers and ordinary people;
(c) To encourage the development of joint projects by all Members or some of them with the projects under formulation and/or consideration by the Members;
(d) To raise general awareness of the status of the work of the Members and to have a framework under which development assistance would be provided and coordinated among the Members and the various contributing agencies; and
(e) To develop a system for training specialists of the Members, transferring and exchanging experience in observation and data processing, and taking advantage of advances in science and technology.

4.2.2 Institutional Arrangement

Coordinated Technical Plan needs institutional arrangements for successfulimplementation. Such arrangements should include mandate, programme management, human resources, funding, sectoral and organizational linkages, and reporting. These are to be considered when formulating the Plan.

4.2.2.1 Countries and organizations involved

Members will work together to contribute towards the implementation of joint programmes and activities, deriving benefits from pooling of resources within the region with the support of WMO and ESCAP.

4.2.2.2 Duration of the Coordinated Technical Plan

Coordinated Technical Plan is to cover a four-year term to keep pace with the financial periods of WMO (4 years) and ESCAP (2 years). The present Coordinated Technical Plan, therefore, covers the period from 2016- to 2019 to coincide with the financial periods of WMO and ESCAP as mentioned above. Coordinated Technical Plan is a live document and continue to be reviewed and updated by the PTC every four years.

4.2.2.3. Regional programmes and projects

Regional programmes or projects involved in the Plan are those that address problems that are common to the whole Panel region. Initial pilot phases may be undertaken in a limited number of countries only. Sub regional programmes and projects are those which address problems that are common to only few Members. Country-specific projects are those which are specifically required by a particular Member to address a problem in that country, given its particular circumstances. Country-specific projects are unique to individual countries and are identified through in-country consultations.

4.2.2.4 Steps for the implementation of the Coordinated Technical Plan

The steps for implementing the Coordinated Technical Plan include:

a. Panel, WMO and ESCAP, through cooperative efforts to assist and/or support the implementation of the Coordinated Technical Plan;

b. Development of projects for implementation by Panel and its Members, and other regional and sub regional economic groups and institutions to implement effectively the Coordinated Technical Plan to enable Members to play their full role in sustainable socio-economic development of their countries.

4.2.3 Reporting

As part of implementation of the Coordinated Technical Plan, Members will report on progress on the implementation of the Plan to the PTC at annual sessions.

4.3. EXPECTED RESULTS AND STRATEGIC ACTIONS

4.3.1 Meteorology

4.3.1.1 Expected Result 1

- Developed capabilities of Members to produce and provide impact based forecasts and risk based warnings of tropical cyclones, storm surges and associated hazards

This is expected to be achieved based on thedevelopment of an efficient and expanded observation and telecommunication network and with acquisition of the latest forecasting technology, improved exchange of data and development of skills of personnel through national, bilateral and regional programs.

4.3.1.2 Strategic Actions

1-a To further improve and expand the observing system of surface, upper-air, ship, buoy, aircraft, radar and satellite observations in the Member countries.

1-b To ensure the real-time operational use of the WMO Information System (WIS) for operation-critical data exchange through dedicated telecommunication means of the GTS, andthrough broadband Internet access for Data Discovery, Access and Retrieval service.

1-c To further increase accuracy, timeliness and usefulness of tropical cyclone forecasts and warnings.

1-d To develop capacity of member countries for providing impact based forecasts and risk based warnings

1-e To extend the operational use of ensemble prediction techniques and probabilistic forecasts for more effective disaster risk assessment and management.

1-f To continue to upgrade the computing facility of RSMC New Delhi and NMHSs so as to facilitate efficient data processing and data assimilation from different observing systems/platforms to suit the national and regional needs.

1-g To ensure the operational use of the recently established a regional storm surge watch scheme to provide Members with the storm-surge advisories including daily marine processed data and information they require for real-time uses

4.3.2 Hydrology

4.3.2.1 Expected Result 2

- Enhanced capabilities of Members to produce and provide better hydrological forecasts and assessments

Members will formulate accurate and timely forecasts and warnings on floods and other water related hazards with a view to supporting preparedness and response mechanisms of their governments and the public.

4.3.2.2 Strategic Actions

2-a To further improve regional cooperation in real time monitoring and exchange of relevant data and information, forecast/products and technical expertise related to hydrological hazards.
2-b To improve flood forecasts and warnings particularly in deltaic and coastal areas by coupling meteorological storm surge forecasts with river flow forecasting.
2-c To enhance regional capabilities relating to flood hazard mapping in delta and coastal regions through continued interaction with the user agencies.
2-d To further improve management of water resources, including assessment of surface and ground water resources in relation to cyclonic disturbances;

4.3.3 Disaster RiskReduction (DRR)

4.3.3.1 Expected Result 3

- Enhanced capabilities of Members to promote tropical cyclone disaster resilient communities through providing guidance on multi-hazard early warning dissemination and response mechanism

Disaster risk reduction in the region will be improved through establishment of institutional and legal frameworks at country level involving improved multi-hazard early warning and Decision support Systems (DSS) of vulnerability and community based disaster risk management (CBDRM) initiatives aiming at enhanced public awareness, and participation of stakeholders to be more effective. These are expected to be achieved through improvement in standard procedures on DRR and exchange of national and international experiences and information on disaster management among the Members.

4.3.3.2 Strategic Actions

3-a To improve regional cooperation in policies and strategies on DRR, especially those related to tropical cyclones, coastal hazards and other extreme weather events.
3-b To establish a regional information system to support development of policies and strategies on DRR as well as interfacing the national level systems by creating an updatedcomprehensive database on disaster information and best practices on DRR.
3-c To further enhance public awareness and appreciation of the impacts of tropical cyclones and other extreme weather events, for possible mitigation and response actions through effective communication with the media prior to, during, and after suchevents.
3-d To further strengthen coordination and interaction between meteorological/hydrological services on the one hand and emergency management/disaster response agencies on the other through integrated emergency management, disaster response and preparedness programmes.
3-e To strengthen regional cooperation on DRR information exchange through networking by making available disaster preparedness and mitigation information through Internet web sites, involving web GIS tools and other means.
3-f To enhance disaster risk management, especially those related to cyclone-related disaster preparedness by developing and implementing pilot projects on multi-hazard disaster risk management programmes into the development plan of the Panel Members in the next four years.

4.3.4 Training

4.3.4.1 Expected Result 4

- Development of a strategic approach to capacity building with a regional perspective

Trainingactivities will be enhanced through strengthening skills of personnel engaged in various aspects of cyclone prediction and early warning through regular training programmes including organization of workshops, seminars, etc.

4.3.4.2 Strategic Actions

4-a To promote training programmes on the use of NWP model products and their application in cyclone (track and intensity) and storm surge prediction.

4-b To promote training programmes on media coordination during disasters and their effectiveness on "human response".

4-c To promote training programmes on the use of remote sensing data including satellite and Doppler Weather Radar products in cyclone forecasting.

4-d To promote visits of experts among Member countries to share their experiences and expertise in cyclone related fields.

4-e To enhance WMO's fellowship support on tropical cyclone and other multi-hazard risk reduction related programmes.

To set up a small group of its Members to develop a draft training plan. The training plan could identify the training needs and available opportunities as well as the gaps that will need to be addressed to support the successful implementation of the Coordinated Technical Plan.

4.3.5 Research

4.3.5.1 Expected Result 5

- Enhanced capabilities of Members to cope with high impact weather through research

Collaboration will be promoted on research activities related to updating forecasting technologies, including NWP, storm surge and flood forecasting models.

4.3.5.2 Strategic Actions

5-a To assess the impact of climate change on tropical cyclones in the region.

5-b To further improve monitoring capabilities to characterize physical and dynamical characteristics of tropical cyclones.

5-b To further improve regional NWP models for tropical cyclone track, Intensity and structure predictions.

5-c To develop and further improve the storm surge and river flood coupling model over specific river basins for forecasting of coastal inundation.

5-d To update vulnerability maps for various parameters like wind force/peak storm surge etc., based on latest available database.

5-e To identify research issues and develop research proposals for technical and funding support

4.3.6 Partnership

4.3.6.1 Expected Result 6

- *Enhanced cooperation among Members and with partner organizations in the provision of forecasts and warnings for tropical cyclones and storm surges*

Partnerships will be further developed both within and outside the region to take advantage of experience, experties, infrastrucfure and other resources, and for future initiatives and development projects.

4.3.6.2 Strategic Actions

a To promote exchange of information and data among Members and with regional bodies to enhance regional cooperation in the five components: meteorology, hydrology, DRR, training and research.

b To enhance cooperation with other regional bodies, organizations, service providers and sectors for more effective provision of the forecasts and warnings.

c To develop and implement joint projects in the areas of the above five components and resource mobilization.

4.3.7 Management and Governance

4.3.7.1 Expected Result 7

- *Effective management and functioning of the Panel.*

Effective manegment and governance will be pursued to ensure fulfillment of Panel's vision, mission and stragic objectives.

4.3.7.2 Strategic Actions

a To further improve the coordination and decision making process of the Panel.

b To enhance effectiveness in implementation of CTP and AOPs.

c To continue to ensure effective and collaborative relationships among working groups of Meteorology, Hydrology and DRR.

d To further improve coordinated technical planning process as well as monitoring and evaluation.

4. 4. ANNUAL OPERATING PLAN

The Annual Operating Plan (AOP) is designed to turn the expected results into specific initiatives and projects which are needed to achieve the expected results. The AOP will contain detailed actions and performance indicators to meet the Strategic Actions of each of the expected results. The AOP will be prepared and adopted at the annual PTC sessions and the detailed actions and performance indicators are subject to revision by PTC during its sessions.

4.5. CONCLUSION

Coordinated Technical Plan (CTP) for the WMO/ESCAP Panel on Tropical Cyclones for the Bay of Bengal and Arabian Sea (2016-2019) has been developed based on the general framework of CTP adopted at the 31st session and the draft CTP submitted to the 32nd session by the CTP Working Group, as well as suggestions from the Panel Members. It also took into account Sendai Framework for Disaster Risk Reduction (2015-2030) adopted during the World Conference on Disaster Reduction in 2015 , the WMO Strategic Plan and the Strategic Plan for the Enhancement of National Meteorological and Hydrological Services in Regional Association II (2012-2016).

CHAPTER-V

Annual Operating Plan for 2016

Coordinated Technical Plan (CTP) for the WMO/ESCAP Panel on Tropical Cyclones - Annual Operating Plan for 2016		
Expected Result	**Strategic Goal**	**Activity**
ER-1 (Meteorology) Enhanced capabilities of Members to produce better forecasts and warnings of tropical cyclones and storm surges.	1-a To improve and expand the observing system of surface, upper-air, ship, buoy, aircraft, radar, wave radar and satellite observations in the Member countries.	To strengthen of the cooperative relationship with the Airlines for development of the regional Aeronautical Meteorological Data Relay (AMDAR) programme (Members, WMO).
	1-b To implement and operate adequate Members' connection to the WMO Information System (WIS) for operation-critical data exchange through dedicated telecommunication means.	Members to implement plans to deploy WIS functionality.
	1-c To increase accuracy, timeliness and usefulness of tropical cyclone forecasts and warnings.	1) To establish and enhance the communication between the operational forecasters in RSMC and the Members (RSMC, PTC-S). 2) To develop collaborative links with the Severe Weather Forecasting Demonstration Project and the Coastal Inundation Forecasting Demonstration Project of WMO (Members, RSMC, BMD, PTC-S, WMO) 3) To promote the use of Common Alerting Protocol (CAP) in partnership with WGDRR (WMO, Members). 4) To implement TC Landfall Forecast FDP (RSMC, Members) 5) To prepare an assessment report on the current status and needs of the Members with respect to data, products, analytical and forecasting procedures.(Working Group on Meteorology in association with RSMC, New Delhi) 6) To arrange the training on Dvorak's technique, microwave imageries & products and application

		of Ensemble Prediction System (EPS) for tropical cyclone monitoring and prediction with the support of WMO. 7) In view of expected expiry of METEOSAT-7, WMO may coordinate to discuss and organize the availability of satellite data and products over the Indian Ocean. 8) WMO/PTC may facilitate training on the utilization of INSAT-3D data and products including RAPID and Nowcasting toolsamong the Member countries.
	1-d To upgrade the computing facility of RSMC New Delhi and NMSs so as to facilitate efficient data processing and data assimilation from different observing systems/platforms to suit the national and regional needs.	RSMC New Delhi may inform the Panel Member countries about the changes/upgradation in their telecommunication systems so that necessary measures taken by the members.
ER-2 (Hydrology) Enhanced capabilities of Members to provide better hydrological forecasts and assessments.	2-a To improve regional cooperation in real time monitoring and exchange of relevant data and information, derived (forecasting) products and technical expertise related to hydrological hazards.	1) To develop and implement regional information exchange strategy during 2016. 2) To organize regional workshops on data transmission mechanisms with special reference to water related hazards. 3) To collaborate with Commission for Hydrology (CHy) and Working Group on Hydrology of RA-II.
	2-b To improve flood forecasts and warnings particularly in deltaic and coastal areas by coupling storm surge forecasts with river flow forecasting.	1) To develop delta hydraulic models for river forecasting by coupling MIKE 11 (or any other model being used in the countries) with the storm surge forecasts for at least one river delta in each country. 2) Developing/application of coastal flood models and associated flood hazard and risk maps in the line as mentioned above. 3) To organize workshops for enhancing the capabilities of the countries.

	2-c To enhance regional capabilities relating to urban floods/ riverine flood risk reduction in delta and coastal regions through continued interaction with the member countries and user agencies.	1) To undertake flood hazard mapping at least in one major delta/coastal area in each country during the next four years. 2) To organize workshops for capacity building. 3) To collaborate and share experiences with Typhoon Committee (WMO, ESCAP, PTC-S)
ER-3 (DRR) Enhanced capabilities of Members to promote tropical cyclone disaster resilient communities through providing guidance on multi-hazard early warning dissemination and response mechanism.	3-a To improve regional cooperation in policies and strategies on DRR, especially those related to tropical cyclones, coastal hazards and other extreme weather events.	a) ESCAP, WMO and PTC to organise capacity development training programme for PTC member countries particularly in the areas of impact based forecasting, risk based warning. b) ESCAP and WMO to work with PTC membercountries for developing regional component of International Network of Multi Hazard Early Warning System (IN-MHEWS) c) ESCAP, WMO and PTC to organise a side event on the occasion of the Asian Ministerial conference on disasater risk reduction, Nov. 2016 in New Delhi.

	3-b To establish a regional information system to support development of policies and strategies on DRR as well as interfacing the national level systems by creating an updated comprehensive database on disaster information and best practices on DRR.	a) To strengthen regional cooperation on DRR information exchange through networking by making available disaster preparedness and mitigation information through Internet web sites, involving web GIS tools and other means. b) ESCAP to organise a capacity development training programme on information management for PTC member countries. c) ESCAP to support PTC member countries for attending regional co-operation related activities including IN-MHEWS, Asian Pacific Centre for Development of Disaster Information Management (APDIM).
	3-c To improve public awareness and appreciation of the impacts of tropical cyclones and other extreme weather events, for possible mitigation and response actions through effective communication with the media prior to, during, and after such events.	ESCAP to support strengthening multi stake holders forum such as monsoon forums, national climate outlook forums in PTC member countries.
	3-d To improve coordination and interaction between meteorological/hydrological services on the one hand and emergency management/disaster response agencies on the other through integrated emergency management, disaster response and preparedness programmes.	ESCAP to continue supporting the initiatives such as Common Alerting Protocol (CAP) in PTC member countries.
	3-e To improve disaster risk management, especially those related to cyclone-related disaster preparedness by developing and	WMO and ESCAP to support piloting a standard methodology project on impact based forecasting and risk based warning in PTC member

	implementing pilot projects on multi hazard disaster risk management programmes into the development plan of the Panel Members in the next four years.	countries.
ER-4 (Training) Training plan for capacity building with a regional perspective.	4-a An expert group of members (Bangladesh, India, Maldives & Sri Lanka)as constituted by 43rd WMO/ESCAP PTC session to prepare draft training plan from 2017-2019.	a) Expert Group to produce a prioritized list of training needs and opportunities of PTC Members through a survey and advise WMO for reporting, planning and implementation purposes. b) The plan to be submitted in the next session of WMO/ESCAP PTC. c) WMO to provide the relevant documents to the expert group and PR of each member country.
	4-b To arrange training programmes on the use of NWP model products and their application in Cyclone (track and intensity) and storm surge prediction.	a) To continue the attachment training programme in RSMC, New Delhi for cyclone forecasters. b) PR of India with WMO to arrange training on storm surge forecasting in India for the PTC member countries. c) To organise a training programme at INCOIS, Hyderabad on utilisation of Ocean data and wave forecasting. d) ESCAP to organise a specialised trailning programme for coastal hazards early warning system in collaboration with RSMC and INCOIS. e) ESCAP to continue supporting training programme for information dissemination and media co-ordination in multi-hazard early warning system.
	4-c To arrange training programmes on the use of Satellite and Doppler Weather Radar (DWR)data & products in Cyclone forecasting as well as DWR callibration and maintenance	
	4-d To arrange training programmes on information dissemination tools and media coordination during disasters and their effectiveness on “human response”.	

	4-e To exchange visits of experts among Member countries to share their experiences and expertise on cyclone & related disaster management aspects.	-
	4-f To enhance WMO's fellowship support on tropical cyclone related programmes.	-
ER-5 (Research) Enhanced capabilities of Members to cope with high impact weather through research.	5-a To produce regional assessment of the impact of climate change on tropical cyclones.	To collect data/materials/papers from the Member countries which are relevant to the regional assessment.
	5-b To develop storm surge and river flood coupling model over specific river basins for forecasting of coastal inundation.	-
	5-c To update vulnerability maps for various parameters like wind force/peak storm surge etc., based on latest available database.	-
ER-6 (Partnership) Enhanced use of forecasts and warnings for tropical cyclones and storm surges for decision making and implementation by Members and partner organizations.	6-a To promote exchange of information and data among Members to enhance regional cooperation in meteorology, hydrology, DRR, training and research.	-
	6-b To enhance cooperation with other regional bodies, organizations, service providers and sectors for more effective provision of the forecasts and warnings.	-
	6-c To develop proposals of joint projects in the areas of five components including resource mobilization.	-
ER-7 (Management and Governance) Effective management and functioning of the	7.a To improve the coordination and decision making process of the Panel.	-

Panel.		
	7.b To enhance effectiveness in implementation of CTP and AOPs.	-
	7.c To ensure effective and collaborative relationships among working groups of Meteorology, Hydrology and DRR.	-
	7-d To improve coordinated technical planning process as well as monitoring and evaluation.	-

CHAPTER-VI

Activities of PTC Secretariat during the Intersessional Period 2015-2016

The activities of PTC Secretariat during the intersessional period 2015-2016 are given below

1. Pursuant upon the organization of 3rd Joint Session of the WMO/ESCAP Panel on Tropical Cyclones (PTC) and ESCAP/WMO Typhoon Committee (TC) (***WMO/ESCAP/PTC-42 Session*** | ESCAP/WMO/TC-47 Session) in Bangkok, Thailand, from 9 to 13 February 2015. PTC Secretariat collected input/feedback from the Panel Member countries and other participating international organizations under the auspicious of WMO and ESCAP and arranged / compiled the PTC-42 final report.
2. In order to enhance the visibility of the of activities of the WMO/ESCAP Panel on Tropical Cyclones beyond the Panel region and to increase its Membership, PTC Secretariat extended invitation to UAE, Qatar and Yemen for participation in the 3rd Joint Session of PTC/TC (Bangkok, Thailand, 9-13 February, 2015). Yemen showed interest for the membership of PTC. PTC Secretariat, under the guidance of WMO, extend full coordinated with Yemen for its membership to Panel on Tropical Cyclones, and extend invitation for attending PTC-43 as an observer.
3. PTC Secretariat collected contributions from Member countries for PTC Newsletters and published PTC Newsletter "Panel News" (Issue No.39, 40) and distributed the e-version issue among the PTC Member countries, WMO, UN-ESCAP and other international organizations.
4. As per decision of 3rd Joint Session of WMO/ESCAP Panel on Tropical Cyclones (PTC) and ESCAP/WMO Typhoon Committee (TC) (Bangkok, Thailand from 9-13 February, 2015), the Japan Meteorological Agency (JMA) organized Attachment Training for three tropical cyclone forecasters one each from PTC Member countries Bangladesh, Maldives, and Myanmar. The Attachment Training was held at RSMC, Tokyo, Japan from 22 to 31 July, 2015. Financial support in lieu of travel and per diem for the participants was arranged through JMA's VCP Fund maintained by WMO. PTC Secretariat, upon WMO's advice, extended invitation to the concerned PTC Member countries for inviting nominations for the attachment training.
5. With the support of the Panel, Secretary of PTC represented PTC at Seventy-first Session of ESCAP (Phase-II) (Bangkok, Thailand from 25-29 May, 2015). The opportunity was also used to share PTC programmes and activities, and to highlight the cooperation of PTC with the other regional body of WMO/ESCAP Typhoon Committee (TC) in joint SSOP project. At the platform of ESCAP, the Secretary of PTC made the following statement:
    a. *"The WMO/ESCAP Panel on Tropical Cyclones (PTC) is working to strengthen regional cooperation among countries affected by tropical cyclones in the Bay of Bengal and the Arabian Sea. This year, a particular highlight of our work is the Joint Session held in cooperation with the ESCAP/WMO Typhoon Committee (TC) and hosted by ESCAP here in Bangkok in February this year. This was the first time in 18 years that such a joint session was held. In this session, the PTC and the TC agreed on mechanism for future cooperation, including joint projects and human capacity building trainings. We are now working to take this positive outcome forward, in cooperation with ESCAP, WMO and Regional Specialized Meteorological Centres."*

6. Panel on Tropical Cyclones Secretariat closely collaborated with the Typhoon Committee in the implementation of joint project "Synergized Standard Operating Procedures (SSOP) for Coastal Multi-Hazards Early Warning System (SSOP)" funded by ESCAP Multi-Donor Trust Fund for Tsunami, Disaster and Climate Preparedness in Indian Ocean and South East Asia. The beneficiary countries include Bangladesh, Cambodia, China, India, Lao PDR, Malaysia, Maldives, Myanmar, Pakistan, Philippines, Sri Lanka, Thailand and Viet Nam. Under this project Manual on SSOP has been developed, the same has been circulated to the Panel Member countries.

7. Concerning to the updation of Tropical Cyclone Operational Plan (TCP-21) for 2015 version, PTC Secretariat collected feedback from PTC Member countries to assist Rapporteur of the Operation Plan in the early issuance of TCP-21 2015 version.

8. In connection to the organization of 43rd Session of WMO/ESCAP Panel on Tropical Cyclones (New Delhi, India from 2-6 May, 2016), PTC Secretariat extended invitation to the Panel Member countries for seeking nomination of their representatives. Invitations were also extended to international organizations like Typhoon Committee, IOC-UNESCO, ICAO, CMA, and Tohoku University, UN-ESCAP, IFRC, RIMES towards their participation as an observer at the PTC-43.

9. As per decision of 3rd Joint Session of WMO/ESCAP Panel on Tropical Cyclones (PTC) and ESCAP/WMO Typhoon Committee (TC) (Bangkok, Thailand from 9-13 February, 2015), the Japan Meteorological Agency (JMA) is organizing Attachment Training for three tropical cyclone forecasters one each from PTC Member countries Oman, Pakistan and Sri Lanka). The Attachment Training will be held at RSMC, Tokyo, Japan from 15 to 26 August, 2016. Financial support in lieu of travel and per diem for the participants was arranged through JMA's VCP Fund maintained by WMO. PTC Secretariat, upon advice by WMO, extended invitation to the concerned PTC Member countries for inviting suitable nominations for the attachment training.

APPENDIX-I
STATEMENT OF PTC SECRETARIAT ACCOUNTS
(2015- 2016)

Sr. No.	**Opening Balance and Receipts**	**Amount (PKR)**
1.	Balance after 42nd Session of PTC	64,545/-
2.	Amount received during the intersessional period (US$ 4000/- equivalent to PKR 418,000/- @US$ 1 = 104.5 PKR)	418,000/-
	Total	482,545/=
	Expenditures	
1.	Services for compilation work of Panel News (Issues No. **39th and 40th**).	40,000/-
2.	Honorarium to Meteorologist-PTC Secretariat @ US$150/= per month (equivalent to Pak Rupees) (for the period from July 2014 to April 2016).	336600/-
3.	Stationery, and other miscellaneous items	10000
4.	Purchase of Colour Toner for Laser Jet printer	Nil
	Total	386600
	Net Balance in hand	95,945

Appendix-II
Final Statement of Panel's Trust Fund

World Meteorological Organization
Organisation météorologique mondiale
Secrétariat
7 bis, avenue de la Paix – Case postale 2300 – CH 1211 Genève 2 – Suisse
Tél.: +41 (0) 22 730 81 11 – Fax: +41 (0) 22 730 81 81
wmo@wmo.int – www.wmo.int

WMO OMM

Weather • Climate • Water
Temps • Climat • Eau

PANEL ON TROPICAL CYCLONE TRUST FUND

Final Statement of Income and Expenditure
For the period 1 January to 31 December 2015
Amounts in US dollars

1.	Balance of fund at 1 January 2015			56,098
2.	Income:			
	2.1 Contributions			
	2.1.1 Bangladesh (26 January 2015)	2,000		
	2.1.2 Maldives (11 March 2015)	3,000		
	2.1.3 Myanmar (30 March 2015)	2,699		
	2.1.4 Pakistan (14 May 2015)	3,000		
	2.1.5 Sri Lanka (21 May 2015)	3,000		
	2.1.6 Tailand (7 August 2015)	3,000		
	2.1.7 Myanmar (20 August 2015)	2,949		
	2.1.8 Total contributions		19,648	
	2.2 Interest		(85)	
	2.3 Total revenue			19,563
3.	Total available funds during reporting period			75,661
4.	Expenditure:			
	4.1 Direct project costs:			
	4.1.1 Travel cost for RANA, 71st Session of te ESCAP Phase II, Bangkok, Thailand, 25-29 May 2015 (Activity no. 80072)	2,641		
	4.1.2 Travel cost for RANA, Tenth Session of the Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System (ICG/IOTWS-X), Muscat, Oman, 24-26 March 2015 (Activity no. 80071)	2,257		
	4.1.3 Temporary Support to the Panel of Tropical Cyclones Secretariat (Activity no. 80070)	4,033		
	4.1.4 Travel costs for ALFARSI, Integrates Workshop of WMO/ESCAP Panel on Tropical Cyclones, Bangkok, 27-29 November 2013 (Activity 80067)	(785)		
	4.1.5 Total direct project costs		8,146	
	4.2 Indirect project costs			
	4.2.1 Support costs (13%)	1,059		
	4.2.2 Write Off (Lumpsum for JAMEEL, Training on Operational Tropical Cyclone Forecasting at RSMC Tropical Cyclone, Dew Delhi (Activity no. 10457))	2,000		
	4.2.3 Unrealized loss on exchange	a/ 541		
	4.2.4 Total indirect project costs		3,600	
	4.3 Total project expenditure			11,746
5.	Balance of fund at 31 December 2015			63,915

a/ WMO's official currency is the Swiss Franc (CHF). Accordingly, all transactions completed in currencies other than the CHF are converted to Swiss Francs at the United Nations Operational Rate of Exchange (UNORE) in force on the day of the transaction. Project account balances (in CHF) are translated to applicable donor reporting currencies based on UNOREs in force at the end of the month to facilitate reporting to donors. As the Swiss Franc has been appreciating against the US Dollar (the reporting currency for the Panel on Tropical Cyclone Trust Fund), foreign exchange gains resulted from conversion of net asset balances from CHF to USD as of the reporting date. This explains the foreign exchange gain. It should be noted that the gain was not realized as of the reporting date, i.e. they were not actual, as they resulted from (a) revaluing the Fund's assets and liabilities as of that date, and (b) converting the resulting CHF balances to USD.

The financial statement has been prepared on the accrual basis of accounting in accordance with the International Public Sector Accounting Standards (IPSAS)

Certified correct:

Luckson Ngwira
Chief, Finance Division
29 February 2016

Appendix -III
Resources and Support

Documents 1

MHEWS SIDS / S E Asia	Canada	10 M CAD	2016- 2019

Document 2

1. Project: Installation of Himwari Cast Receiving and Processing Systems

Geographic region: East Asia, Pacific

Donor	Japan Meteorological Agency (JMA)
Trust Fund Code(s)	420280
Grant	CHF 741,546
Governance	Project Executive(s) Kuniyuki Shida (SPM/RC), Ayşe Altunoğlu (H/PCU)
Focal Point	Ryuji Yamada (PM/RAP)
Duration	January 2015 – March 2016
Received funds	CHF 714,546
Project implementation (%)	90%
Budget implementation (%)	90% *(note: payment to the vendor is imminent – services received and payment will be made in February 2016)*

Summary

Procurement and installation of the new Japanese HimawariCast Receiving and Processing systems in nine (9) countries: Bangladesh, Cambodia, Federated States of Micronesia, Myanmar, Palau, Papua New Guinea, Thailand, Tuvalu and Viet Nam. Additionally, skills development of staff of the relevant NMHSs in the recipient countries to enable them to sustainably operate the installed systems.

Key highlights (covering reporting period)

- The equipment for the project was shipped to all 9 recipient countries;
- The supplier installed the systems in 8 countries (Bangladesh, Cambodia, Federated States of Micronesia, Myanmar, Palau, Thailand, Tuvalu and Viet Nam) during October-December 2015;
- Due to the delay in the customs clearance and tax exemption process in Papua New Guinea (PNG), the installation of the system has not taken place in this country;
- However, a series of discussions with the Meteorological Services in PNG has given assurance that the equipment will be released from customs early 2016.

Actions to be taken

- Given that almost all recipient countries have received the equipment, WMO to prepare 'Transfer of Title' to ensure that the equipment becomes legally the property of the respective recipient country, thus, giving full ownership for the operation of the system;;
- Follow up with the Meteorological Services of PNG to ensure that equipment is released from customs as early as possible;

- Hold discussions with the donor, JMA, regarding their intension of requesting the addition of more recipient countries (country identification; funding is available in the Trust Fund);
- Prepare final narrative and financial report on the project expected to be completed in March 2016;
- Prepare a draft WMO press release on the project and the recipient countries (focusing on the impact based forecasting potential offered by the system).

2. Project: Installation of a Doppler radar system in Sri Lanka

Geographic region: Asia

Donor	Government of Sri Lanka
Trust Fund Code(s)	421109
Grant	USD 2,931,480
Governance	Project Executive Robert Masters (D/DRA)
Focal Point	Kuniyuki Shida (SPM/RC)
Duration	May 2007 - December 2016
Received funds	USD 2,931,480
Project implementation (%)	60%
Budget implementation (%)	52 %

Summary

Procurement and installation of a Doppler weather radar system for the Department of Meteorology of Sri Lanka.

Key highlights (covering reporting period)

- No highlights for this reporting period.

Actions to be taken

- Pending the receipt of the response from the Ministry of Disaster Management and taking into consideration that the new Minister and the Secretary of the Ministry of Disaster Management were appointed in October 2015 after the general election in the country in August and Prof. Taalas assumed the post of SG of WMO on 1 January 2016, a new WMO letter to the Secretary of the Ministry of Disaster Management will be sent in January 2016 to expedite the response from Sri Lanka;
- The Ministry of Disaster Management will send an official letter to WMO confirming that the damaged equipment should be repaired using the remaining funds in the Trust Fund;
- Once agreed by Sri Lanka and WMO, the current PO will be revised to accommodate proposed actions.
- DOM will send the equipment back to the factory of EEC for inspection. EEC will submit the cost proposal to WMO;
- EEC will repair the damaged equipment and send the equipment back to DOM with some replacements;
- The radar system will be installed at the radar site;
- In parallel, the relevant authorities of Sri Lanka including DOM should conduct the construction work to repair the damage road leading to the radar site.

APPENDIX-IV
TERMS OF REFERENCE OF THE PTC WORKING GROUP ON METEOROLOGY (WGM)

In order to coordinate efforts in the implementation of various programmes and activities related to meteorology with the aim to better support the socio-economic development process in the PTC region and to help accomplish the strategic goals and objectives as mentioned under the Meteorological Component of the Coordinated Technical Plan of the WMO/ESCAP Panel on Tropical Cyclones (PTC) for the Bay of Bengal and the Arabian Sea, the PTC has established the Working Group on Meteorology (WGM) as decided during 39th Session of PTC (Myanmar, 5-9 March, 2012) with the following Terms of Reference and operational modalities.

Terms of Reference

The WGM will promote cooperation among the Members in the implementation of various programmes and activities under the Meteorological Component of the PTC's Coordinated Technical Plan with the aim to support the socio-economic development process and enhance cooperation among the Members in all the five major components towards this end. The WGM is expected to advise and assist the PTC in:

- Identifying priority issues and areas of cooperation in the Meteorological Component;
- Promoting and facilitating the exchange of experiences and knowledge on the latest developments and techniques related to the above issues and areas;
- Coordinating and implement priority activities and programmes of the PTC aiming at strengthening capacity of the Members in meteorology;
- Mobilizing resources to carry out priority activities of the PTC related to the Meteorological Component;
- Developing Annual Operating Plan (AOP) for meteorology and reporting on the activities under the AOP;
- Reporting overall progress in the implementation of the Meteorological Component of the PTC's Coordinated Technical Plan;
- Recommending to the PTC's priority areas, programmes and activities for cooperation in meteorological research by related experts of the Members; and
- Performing any other task as assigned by the PTC.

Membership

The WGM consists of the following members:

- Mrs. Sunitha Devi, India as Chairperson
- Mr. Khalid Ahmed Al-Wahaibi, Oman as Vice-Chair
- Mr Ali Shareef, Maldives as Vice-Chair
- Members of other 6 countries

The PTC invites WMO and ESCAP to continue their involvement in the work of WG-M. The PTC also requests the other concerned agencies to participate in the activities of WGM. The term of service on the WGM is 1 year, which shall be automatically extended for similar durations unless modified or terminated by the PTC.

Operation modalities

In view of the limited financial resources of the PTC Trust Fund, the WG-M is expected to perform its work through email and other means. The WGM shall hold meeting during the annual Session of PTC. The WG-M members, however, may also meet during the inter-sessional period, if so necessary.

Reporting requirements

The Chairperson of the WGM is required to report to the PTC on overall progress in the implementation of the Meteorological Component of the Coordinated Technical Plan as well as on the activities with regards to the AOP for meteorology through the PTC Secretariat to the PTC Chairperson and the PTC Members for their consideration under the framework of the PTC. This report may also include recommendations related to priority activities to be undertaken in the coming years.

TERMS OF REFERENCE OF THE PTC WORKING GROUP ON HYDROLOGY (WGH)

In order to coordinate efforts on the implementation of various programmes and activities related to hydrology with the aim to better support the socio-economic development process in the PTC region and to help accomplish the strategic goals and objectives as mentioned under the Hydrological Component of the Coordinated Technical Plan of the WMO/ESCAP Panel on Tropical Cyclones (PTC) for the Bay of Bengal and the Arabian Sea, the PTC has establishedWorking Group on Hydrology (WGH), as decided during 39th Session of PTC (Myanmar, 5-9 March, 2012) with the following Terms of Reference and operational modalities.

Terms of Reference

The WGH will promote cooperation among the Members in the implementation of various programmes and activities under the Hydrological Component of the PTC's Coordinated Technical Plan with the aim to support the socio-economic development process and enhance cooperation among the Member in all the five major components towards this end. The WGH is expected to advise and assist the PTC in:

- Identifying priority issues and areas of cooperation in the Hydrological Component;
- Promote and facilitating the exchange of experiences and knowledge on the latest developments and techniques related to the above issues and areas;
- Coordinating and implement priority activities and programmes of the PTC aiming at strengthening capacity of the Members in hydrology and water resources;
- Mobilizing resources to carry out priority activities of the PTC related to the Hydrological Component;
- Developing Annual Operating Plan (AOP) for hydrology and reporting on the activities under the AOP;
- Reporting overall progress in the implementation of the Hydrological Component of PTC's Coordinated Technical Plan;
- Recommending to the PTC's priority areas, programmes and activities for cooperation in hydrological research by related experts of the Members; and
- Performing any other task as assigned by the PTC

Membership

All Member countries will be represented at the WGH.

Pakistan, Myanmar, Bangladesh will be the Chair and Vice-chairs of the WGH respectively. The PTC invites WMO and ESCAP to continue their involvement in the work of WGH. The PTC also requests to other concerned agencies to participate in the activities of WG-H.

The term of service on the WGH is 1 year, which shall be automatically extended for similar durations unless modified or terminated by the PTC.

Operation Modalities

In view of the limited financial resources of the PTC Trust Fund, the WGH is expected to perform its work through email and other means. The WG members shall meet if necessary.

Reporting Requirements

The Chairperson of the WGH is required to submit annual report on WGH activities with regards to the implementation of Coordinated Technical Plan through PTC Secretariat to the PTC Chairperson and the PTC Members for their consideration under the framework of the PTC. This report will include recommendations related to priority activities to be undertaken in the coming years.

TERMS OF REFERENCE OF THE PTC WORKING GROUP ON DRR (WGDRR)

In order to coordinate efforts on the implementation of various activities under the Disaster Risk Reduction (DRR) Component to better support the socio-economic development process in the Panel on Tropical Cyclones (PTC) Area and to help accomplish the DRR related goals and objectives in the Coordinated Technical Plan (CTP) 2009-2011, PTC established the Working Group on Disaster Prevention and Preparedness, later renamed to the Working Group on Disaster Risk Reduction (WGDRR), with the following Terms of Reference and operational modalities.

Terms of Reference

The WGDRR will promote cooperation among the PTC Members in the implementation of activities under the DRR Component of the PTC's Coordinated Technical Plan to support the socio-economic development process and enhance cooperation among the Members inall the five components towards this end, the WGDRR is expected to advise and assist the PTC:

- Identifying priority issues and areas of cooperation in the DRR Component;
- Promoting and facilitating the exchange of experiences and knowledge on the latest developments and techniques related to the above issues and areas;
- Coordinating and implementing priority activities of the AOP and programmes of the PTC aiming at strengthening capacity of the Members in DRR;
- Mobilizing resources to carry out priority activities of the PTC related to the DRR Component;
- Monitoring and evaluating overall progress in the implementation of the DRR Component of the Coordinated Technical Plan;
- Recommending to the PTC priority areas, programmes and activities for cooperation in DRR research by experts of the Members;
- Promoting measures for more effective cooperation with other components of work of the Panel, including the development of the conceptual framework on multi-hazard early warning systems and public outreach programs; and,
- Reporting overall progress in the implementation of the DRR component of the CTP.

Membership

The WGDRR will consist of the following members:

- Mr. Adthaporn Singhwichai, Thailand; as Chairperson
- Mr. Captain Faisal, Oman; as Vice Chairperson
- Members of other 7 countries

The PTC invites ESCAP and WMO to continue their involvement in the work of WGDRR. The PTC also requests the other concerned agencies to participate in the activities of WGDRR.

The term of service on the WGDRR is 1 year, which shall be automatically extended for similar durations unless modified or terminated by the PTC.

Operation modalities

In view of the limited financial resources of the PTC Trust Fund, the WGDRR is expected to perform its work through email and other means. The WG members shall meet if necessary.

Reporting requirements

The Chairperson of the WGDRR is required to submit an annual report on DRR activities with regards to the implementation of Coordinated Technical Plan through the PTC Secretariat to the PTC Chairperson and the PTC Members for their consideration under the framework of the PTC. This report will include recommendations related to priority activities to be undertaken in the coming years.

APPENDIX-V

TERMS OF REFERENCE FOR THE PANEL ON TROPICAL CYCLONES SECRETARIAT

The Panel on Tropical Cyclones (PTC) Secretariat will coordinate the Panel's programme in close consultation with the WMO and ESCAP Secretariats. The PTC Secretariat will report to the Panel at regular intervals on the progress of the work so far undertaken. Specifically, to the extent that its available resources permit, the PTC Secretariat shall:

(1) Assist the Members as administrative, documentary, and information centre of the Panel on Tropical Cyclones;

(2) Implement the PTC decisions and coordinate and monitor the implementation of the PTC Annual Operating Plan;

(3) Maintain close contact with the Panel Members and other relevant organization by correspondence and coordination to carry out all matters related to implementation of recommended programmes;

(4) Follow up decisions of Panel meetings and related activities such as those concerning other regional tropical cyclone bodies, or the General Component of the WMO Tropical Cyclone Programme (TCP) with assistance from WMO;

(5) Manage the operation and promote the use of the PTC website;

(6) Participate and organize the annual session of the Panel with assistance and guidance from WMO/ ESCAP including documentation;

(7) Process and take necessary action promptly on correspondence from Panel Members, WMO, and other sources;

(8) Enhance visibility of the PTC in cooperation with Panel Members including editing and publishing of PTC news Letter;

ANNEX VI

SUPPORT FOR THE PANEL'S PROGRAMME

International Network for Multi-Hazard Early Warning Systems (NM-HEWS) in Asia and the Pacific (Submitted by UN-ESCAP)

In the last decade, the Asia-Pacific region had 1,624 reported disasters. From these, approximately 400,000 people lost their lives, and around 1.4 billion were suffered.[10] Disasters continued to undermine hard-won development gains across the region, and impacts of disasters constitute a serious threat to the attainment of the Sustainable Development Goals (SDGs), and thus, in the Asia-Pacific, building resilience to disasters is not a matter of choice.

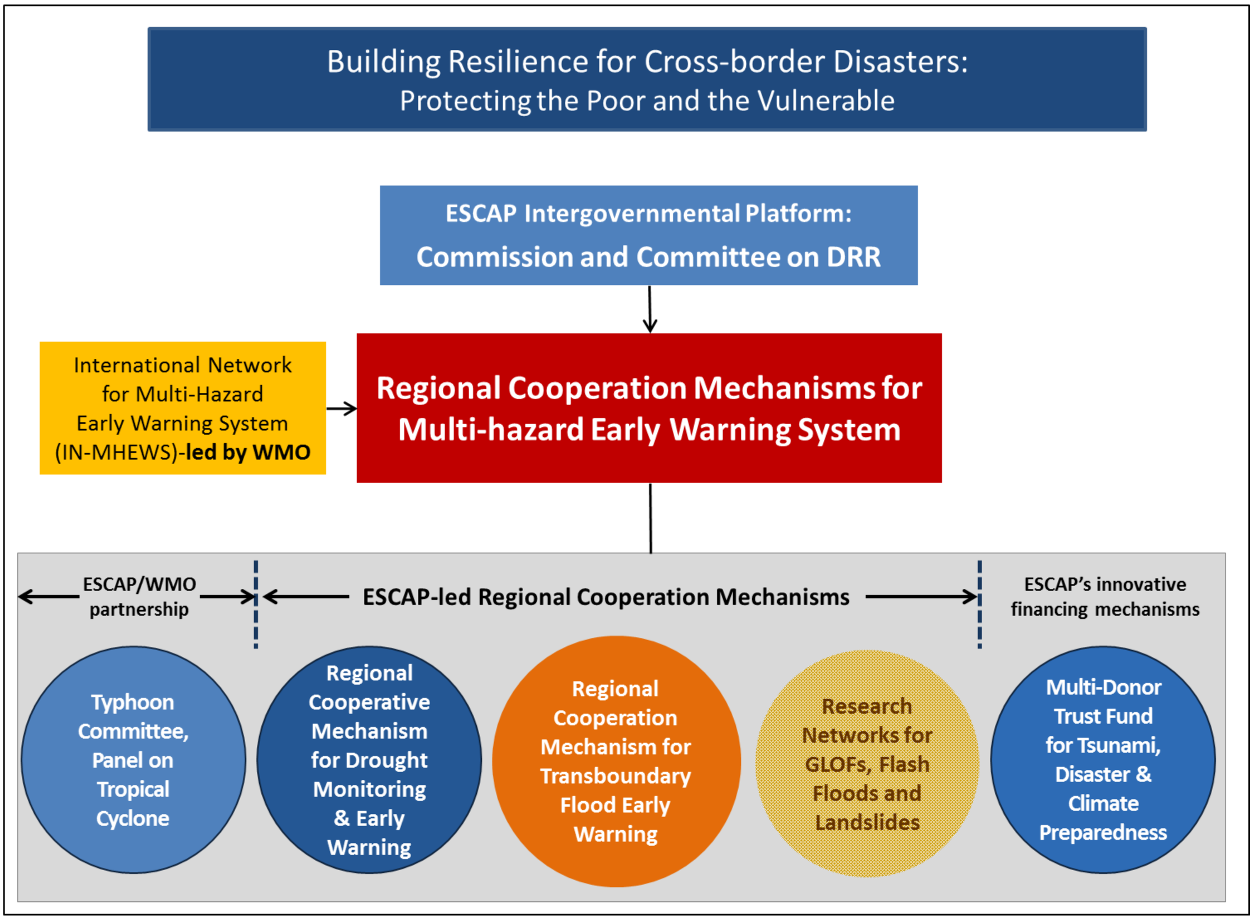
Establishing proper early warning systems is a critical element in protecting our development gains, and the *Sendai Framework for Disaster Risk Reduction 2015-2030*(the Sendai Framework) recognizes the importance of early warning systems (EWS) in reducing the disaster risk. These early warning systems should cover multi-hazards considering the cascading impacts of natural hazards and climate change. Accordingly, the Sendai Framework calls for enhancing and strengthening multi-hazard early warning systems (MHEWS).

In response to this call, the **International Network for Multi-Hazard Early Warning Systems (IN-MHEWS)** is being established as a multi-stakeholder partnership that will facilitate the sharing of expertise and good practices for MHEWS. As a broad-based networking initiative on early warning, IN-MHEWS is not meant to be an operational network of MHEWS. Instead, it will exemplify the importance of multi-stakeholder cooperation in MHEWS as a way to advocate the implementation and/or improvement of multi-hazard early warning systems, to compile and disseminate lessons learned regarding early warning systems, and to increase the efficiency of investments in MHEWS for societal resilience.

Member States of ESCAP also recognized the need to strengthen people-centred multi-hazard early warning systems and requested the ESCAP secretariat to work on multi-hazard early warning systems at the regional level through the Commission resolution 71/12 adopted in May 2015. Accordingly, ESCAP outlined a concept multi-hazard early warning system as the regional component of WMO-led IN-MHEWS, based on ESCAP's experience in regional mechanisms including

- Panel on Tropical Cyclones,
- Typhoon Committee, and
- Regional Drought Mechanisms and Multi-donor Trust Fund on Tsunami, Disaster and Climate Preparedness.

ESCAP's new initiatives on regional cooperation mechanism for flood forecasting and early warning in transboundary river basins, and putting in place a research network(s) for flash floods, GLOFS and landslides highlight its ongoing efforts towards strengthening multi-hazard regional early warning systems in the region (Figure).



ESCAP with partners has also developed the tools for multi-sectoral impact assessment of slow-onset disasters - which were used for 2015/2016 El Nino Impact Outlook in Asia and the Pacific.

Under the agenda item 9.4, the concept will be presented for the discussion with PTC member Countries.